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Investigating Engineering Practice is Valuable for Mathematics Learning

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Investigating engineering practice is valuable for mathematics learning

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While engineering mathematics curricula often prescribe a fixed body of mathematical knowledge, this study takes a different approach; second-year engineering students are additionally required to investigate and document an aspect of mathematics used in engineering practice. A qualitative approach is used to evaluate the impact that students' investigations have on their mathematics learning and whether this approach creates greater value for students compared to curriculum mathematics learning. This article contains an account of students' engagement with and their emotional responses to their investigations of professional engineers' mathematics usage. The study illustrates the positive changes in students' mathematics attitudes arising from their insights into engineering practice. Students have acquired a sense of wanting to learn mathematics: they now see themselves as learners preparing for their future careers. This study also introduces students to the concept of communicating mathematics.

1. Introduction

Value is an important concept in mathematics education. It is arguable that lecturers, especially in engineering faculties, know little about the relationships that students form with mathematics; for example, what value engineering students place on mathematics learning.

Understanding modern students' motivation to learn has value for educators; for example, Richard Skemp (1987) asks 'why should anyone want to learn mathematics?'. His response is 'motivation . . . towards satisfaction of some need' and in the classroom short-term motivations are 'the desire to please the teacher and the fear of displeasing her or him' (Skemp, 1987). Paul Ernest also asks 'what is the purpose of teaching and learning maths?' He believes that the aims of teaching mathematics 'can be a hotly contested area'. An absolutist-like view of 'giving students mainly unrelated routine mathematical tasks which involve the application of learnt procedures, and by stressing that every task has a unique, fixed and objectively right answer, coupled with disapproval and criticism of any failure to achieve this answer' lead to 'mathephobia' or a feeling that 'mathematics is cold, hard, uncaring, impersonal, rule-driven, fixed and stereotypically masculine' (Ernest, 2004).

While many lecturers recognize the importance of student motivation, the notion of students' value of mathematics is not as apparent. Many undergraduate engineering students reluctantly engage in the subject only because it is mandatory. In this study, mathematics relationships are studied in the context of Wigfield and Eccles' social cognitive expectancy-value model of achievement motivation. This theory posits that predictors of achievement behaviour are: expectancy (Am I able to do the task?); value (Why should I do the task?); students' goals and schemas (short- and long-term goals and individuals' beliefs and self-concepts about themselves); and affective memories (previous affective experiences with this type of activity or task) (Wigfield & Eccles, 2002; Schunk *et al.*, 2010). Expectancy-value research has substantiated that students with positive self-perceptions of their competence and positive expectancies of success are more likely to perform better, learn more and engage in an adaptive manner on academic tasks by exerting more effort, persisting longer and demonstrating more cognitive engagement. Students who value and are interested in academic tasks are more likely to choose similar tasks in the future. Interest refers to the liking and wilful engagement in an activity. Interest can be: personal (personal enjoyment or importance of specific activities or topics); situational (interestingness of the context e.g. novel versus textbook); or psychological (heightened interest when personal interest interacts with situational interest) (Wigfield, 1994; Wigfield & Eccles, 2000, 2002; Schunk *et al*., 2010).

2. Transition from engineering education to engineering practice

It is claimed that 'the transition through life, from school to university, is multifaceted . . . it is a process that, if successful, includes the later transition to professional work, while potentially inspiring deep learning along the journey . . . a clear understanding of where they [students] are heading can inspire this deeper engagement' with mathematical ideas (Wood & Solomonides, 2008). Booth (2004) found that students' perceptions of mathematics have a considerable influence on their responsibility for and approach to mathematics learning. Students with a realistic perspective of the role of mathematics 'integrated into programme of study' and 'into the world it describes' demonstrate a deeper learning approach compared to students who view mathematics as an 'isolated subject' (Booth, 2004). Similarly, Petocz and Reid (2006) found that students' perceptions of mathematics in their future profession influence their approach towards learning mathematics in university, however, other studies also show that 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).

Gainsburg contrasts the mathematical disposition of engineers with the disposition developed in schools (Gainsburg, 2007). Furthermore, adjusting to the workforce can be problematic for many students as they discover what they learned in university needs to be contextualized for work (Wood, 2010). The gap between engineering education and engineering practice is also highlighted by Trevelyan (2010) who asserts that it takes up to 3 years for a novice engineer to become reasonably productive in a commercial context. Engineers, with between 5 and 20 years of engineering experience, identify 'communication, teamwork, self-management and problem-solving' as critical competencies required for their work (Male *et al.*, 2010). Research shows that social issues such as communications and team work contribute significantly to the gap between engineering education and engineering practice (Tang & Trevelyan, 2009). The scarcity of systematic research on engineering practice makes it difficult for educators who wish to design learning experiences to enable students to manage the transition into commercial engineering contexts more easily (Cunningham *et al.*, 2005; Trevelyan, 2011). Similarly, to provide 'a mathematical education of engineering students, which is relevant for their later work as engineers, one needs studies that try to capture the mathematical expertise of engineers' (Alpers, 2010).

3. Engineering education in a social context

The importance of positive social interactions in mathematics classrooms is well established; better mathematical learning can be achieved through mathematical discussion, emotional support and sharing of knowledge and skills (Ingram, 2008). Similarly mathematics can be made more accessible in classrooms which encourage exploration, negotiation and ownership of knowledge due to enhanced relationships (Black *et al*., 2009).

A study of practising engineers found that, for many engineers, mathematics was much more challenging at university than school. One engineer missed the ‘banter’ of ‘the peer group that studied together’ in school and he maintains that in college ‘the social element of the maths was gone’. Another engineer used a type of peer learning to learn mathematics in university: he says there were ‘a lot of us putting our heads together trying to get solutions’. A further engineer who ‘would not dare ask a question out loud in a lecture’ attended tutorials where ‘the post-grads would come and just talk to you’, studying with her boyfriend also helped (Goold & Devitt, 2012).

4. Methodology

The main objective of this study is to investigate whether students’ mathematics learning benefits from increased knowledge of mathematics used in engineering practice. Secondary objectives include engaging students in independent research and mathematics communications.

The population of interest is a class group of 17 second-year part-time environmental engineering degree students taking ‘Technical Mathematics 3’. The group is all male and comprises a diversity of student ages. Many of the group work part-time in engineering and trades environments: typical careers include electricians, carpenters, plumbers and builders. Technical Mathematics 3 topics include number bases, logic circuits, probability and reliability, differentiation, investigating functions using differentiation, software skills and matrices. The students’ prior mathematics learning in Year 1 includes statistics, vectors, functions, models, trigonometry and mathematics software. Students use little mathematics in their work, for example, when asked how much mathematics he uses at work, one student replied ‘not that much, occasionally, I would be measuring cable installations and using calculations to find suitable MCBs [circuit breakers] for projects; nothing like reliability or anything like that’.

In parallel with Technical Mathematics 3 students take the following modules: Electrical Power Systems (e.g. domestic/light industrial electrical installations, renewable electricity generation, potentially explosive atmospheres and large-scale electrical distribution systems); Power Generation (e.g. gas turbine power plant, performance of gas turbine, steam turbine and combined cycles, payback period for power plant installations, layout and the functioning of a nuclear power plant and safety); Global Environment (e.g. sustainability and climate change, factors impacting the environment, water resources, water pollution and air pollution); and Traditional Energy Sources (e.g. fuel sources, exploration and extraction of resources, processing technologies, transport to markets, health, safety and environmental issues) modules. Only two of these subjects involve the direct use of mathematics: Electrical Power Systems to perform fault calculations and to determine battery characteristics such as storage capacity, charge and discharge rates and longevity with different usage cycles; and Power Generation to calculate performance of turbines and to calculate the payback period for power plant installations. There is no mathematics module in the following semester, however students use mathematics in Energy Control Systems and they also use simple mathematics to do financial analysis.

This study incorporates an assignment into Technical Mathematics 3 that accounts for 20% of the module’s marks. This replaced the software skills assessment; students had in a prior mathematics module successfully completed Excel and Matlab assessments. This study was approved by the course co-ordinator and generally viewed as engineering applications education and a teaching innovation study. The remaining Technical Mathematics 3 assessment includes written examination (55%), key skills testing (15%) and a reliability analysis project (10%).

Linking students' mathematics learning with mathematics used in professional engineering practice is a central theme in this study. Mathematics communication is a secondary theme. Students are required to individually investigate and document an aspect of mathematics used in engineering practice. They are also required to create a poster illustrating their findings, give a short presentation and answer questions. A copy of the assignment is included in Appendix A. The study is designed to allow students take control of their own learning by choosing mathematics topics that interest them. Students are also free to use their own preferred methods to conduct their research and communicate their ideas and findings. Survey questionnaires are used to capture the students' feelings about mathematics and mathematics learning before and after they engage in their research. Students are also asked to describe their mathematics learning strategy, the importance of mathematics in their lives, the relevance of mathematics to other subjects, the role of mathematics in their future careers and any engagement with mathematics outside of lecturers. The before and after survey instruments are included in Appendices B and C, respectively.

The data are analysed qualitatively using a system of open coding (Silverman, 2010). This involves grouping together sections of survey responses that share some common meaning, for both the before and after survey responses. The findings result from the subsequent emergence of distinctive themes from the coded data. Students' comments are also recorded.

5. Results

Interest and familiarity are the main factors in students' choice of mathematics topics. Google searches and mathematics text books are the main sources of information used by students to conduct their research. The range of topics presented by students includes all the main mathematics domains: algebra, geometry, trigonometry, statistics and numbers. Examples of mathematics used in engineering practice that were reported include:

- The ubiquitous use of algebra in all engineering applications and particularly for calculating flow rates and expansion of pipe materials due to heating
- Mathematics required to design 'safe' bridges
- The many angles visible in a major local road junction improvement project
- The importance of numerical data analysis in environmental engineering
- Statistical methods for product and process improvement
- The cost benefit of reliability analysis in engineering product design applications
- Modelling complex environmental engineering systems and risk analysis
- Using vectors to determine blade movement in a wind turbine

Statistics is the most popular topic, probably because students were learning statistics at the time. It is noticeable that only one student sought assistance from a practising engineer; his project determined the geometry required to design a visual level indicator for a tilted diesel storage tank.

In addition to writing about their chosen applications of mathematics in engineering practice, students produced posters to illustrate their work. Sample posters are illustrated in Figures 1, 2 and 3.

6. Findings

6.1 Prior to engaging in the assignment

6.1.1 Finding 1 The majority of the class of engineering students in this study are neither confident in their mathematics ability nor demonstrate any value of mathematics other than for the purpose of passing examinations.

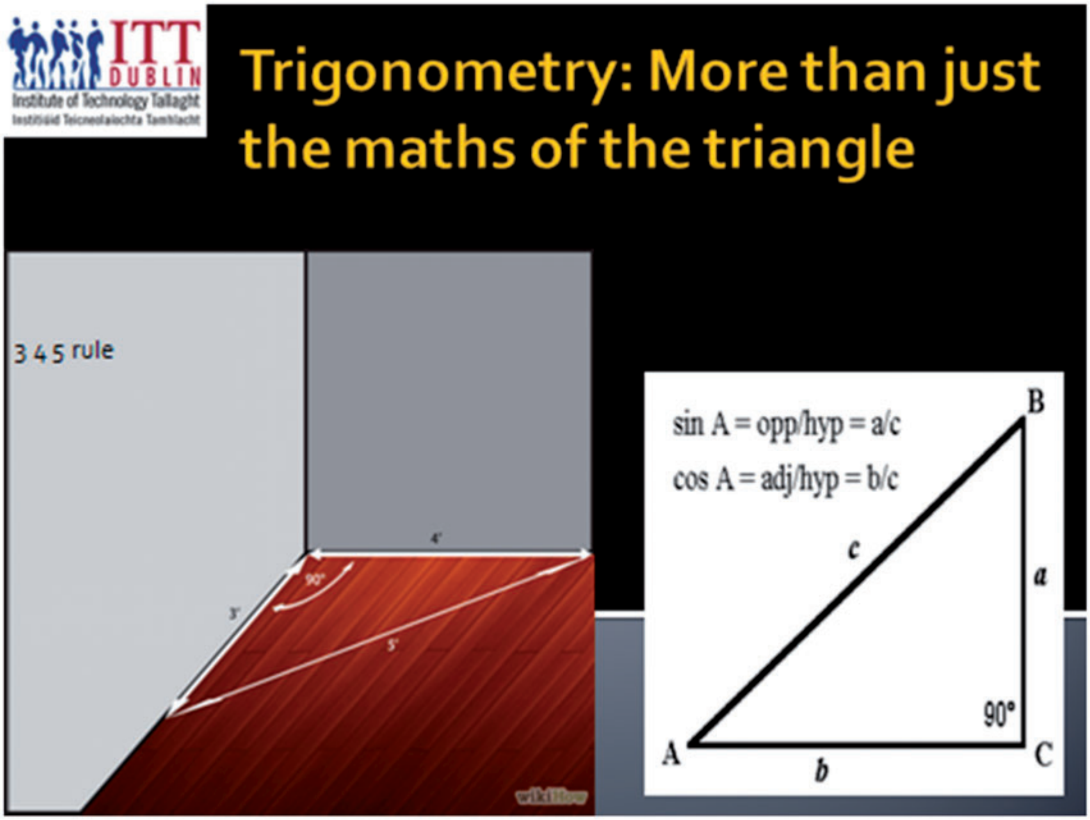

FIG. 1. Student poster: 'Trigonometry: More than just the maths of the triangle'. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.

It is observed that the majority of students' feelings about mathematics have some degree of negativity. Students' lack of confidence and the perceived difficulty dominates students' feelings about mathematics, for example:

- 'I like it [mathematics], I just wish I understood it better'
- 'I don't like it as I find it difficult and hard to understand'
- 'I'm not confident . . . I often make mistakes'
- 'I don't like maths at all, probably because I find it difficult'
- 'It is my least favourite subject; most of questions and theories are very difficult to understand unless they are well instructed'
- 'I am really interested in maths, sometimes I find it difficult but I understand it'

Only one of the 17 students is unreservedly positive about mathematics:

- 'I like maths, I like the logic behind it'

6.1.2 Finding 2 Students present mathematics learning as a chore, they have no mathematics goals and their mathematics learning comprises of repetitive memorization of solutions to past examination questions.

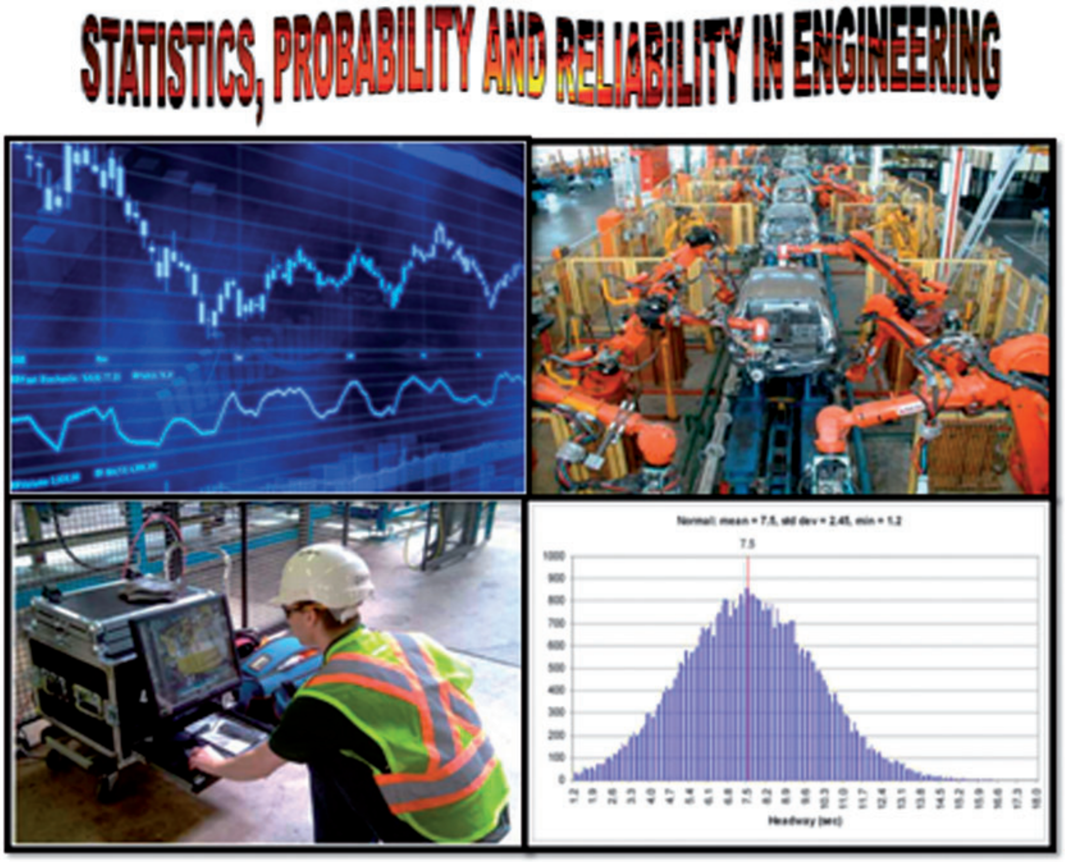

FIG. 2. Student poster: ‘Statistics, Probability and Reliability Engineering’. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.

Students do not exhibit positive mathematics relationships: they do not show commitment to the ongoing process of learning and they do not demonstrate any mathematics learning goals. The students’ only learning strategy is practising past examination questions, for example:

- ‘I don’t have a strategy, I just go by past exam questions . . . repetition but it is hard because there is so much to cover’
- ‘I have not got a maths strategy . . . just questions and past exam papers’
- ‘I try to understand the step by step solutions to exam questions, repetition is essential’
- ‘practice, practice, practice . . . doing past exam questions with detailed steps and solutions’

6.1.3 Finding 3 There is no evidence of social interaction in the students’ mathematics learning; students only discuss how irrelevant mathematics is to their lives.

It is noted that students’ mathematics discussion is sparse and negative, for example:

- ‘I never discuss maths outside of lectures’

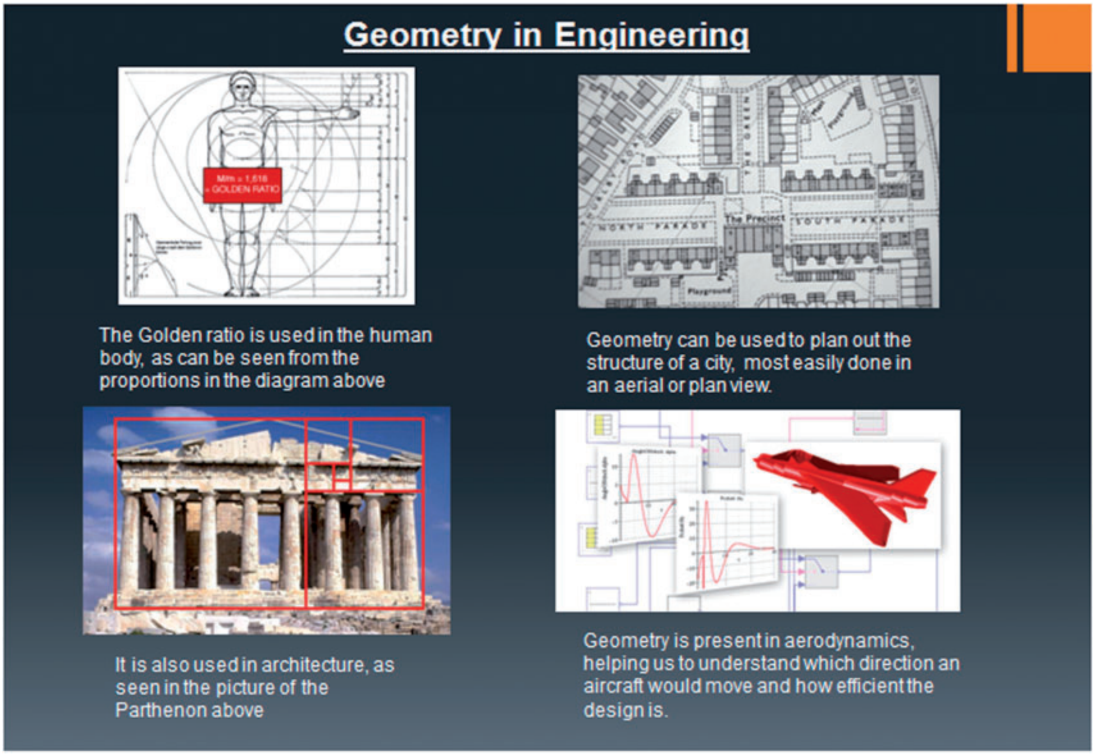

FIG. 3. Student poster: 'Geometry in Engineering'. This figure appears in colour in the online version of *Teaching Mathematics and its Applications*.

- 'I often discussed how irrelevant maths topics are to our future careers'
- 'We discuss how bad maths actually is and question why do we need it'
- 'Not many discussions, nobody wants to talk about maths'

There is no evidence of student collaboration during the assignment. While students individually sought clarification about the assignment, their difficulty communicating mathematics is evident; in particular, students show a distinct reluctance to engage in documenting their methodology and feelings as required in the assignment. Students also show a reluctance to depart from rules or 'set procedures' and from seeking a precise goal such as the 'correct answer' in traditional mathematics learning. For example, the student who devised a formula to calculate the volume of diesel in a tilted storage tank shows satisfaction with his formula. However, this student also shows a reluctance to write a report in the format specified in the assignment sheet; his expectation is to be awarded 100% solely because he derived a formula. While there is no questioning the actual mathematics employed, the value of the mathematics is lost in the absence of clear communication.

6.2 Following completion of the assignment

6.2.1 Finding 4 Students show improved relationships with mathematics. In particular, they demonstrate an increased awareness of the usefulness of mathematics in their future careers. It is noted that the new awareness of the relevance of mathematics in life and work energises students to 'work harder'.

Subsequent to completing the assignment, students showed a new interest in mathematics learning in lectures and particularly in applications of course topics in the real world. Students, without instruction, 'googled' applications of subsequent lecture topics and voluntarily contributed their findings to the class. The new eagerness to engage more in mathematics learning is also evident from the students' completed questionnaires:

- 'I was sceptical as to how much of the maths we are studying would come into use again . . . I saw real life ways of applying maths . . . I saw the relevance of trigonometry and how it can be used to calculate many different things in relation to engineering . . . maths is one of the key ingredients of engineering and I now know to try my hardest to master the discipline so that I can become the best engineer I can'
- 'Mathematics has been one of my more difficult modules since starting this course . . . I have found maths the most difficult subject to self-learn . . . I have now realised that at a touch of a button and from the help of Google and similar websites, the information I need and more is available . . . I have been introduced to a whole new way of learning and retrieving information'
- 'The assignment has taught me to work harder at maths as I need good maths level to become an engineer'

Another observation is the increased classroom discussion about mathematics arising from the assignment. This is evidenced by students' interest in each other's posters and presentations. However, it is noted that students are challenged by the departure from 'set procedures' and getting the 'correct answer'. For example, students wanted to do mathematics; they wanted to write mathematics equations and formulae and solve mathematics problems; they did not want to write words. They verbally expressed concern when repeatedly directed towards describing mathematics applications in real-world engineering situations. Furthermore, when asked if they liked the exercise, students' responses include:

- 'I didn't because I didn't know how to do it properly . . . what is the expectation?'
- 'It's different, questions are too abstract'
- 'Not particularly, I found it difficult to write about something which I didn't particularly like'
- 'Difficult to put mathematical equations into a word document'
- 'Not all of it, parts of it were too abstract, not sure what relevance it has to course'
- 'It was very difficult to do it, I didn't even know how should I start'

While some students are uncomfortable with the concept of an investigative approach to mathematics learning and report writing, all students state that they benefitted from the exercise. In particular, it is noted that students' investigations of mathematics used in engineering practice creates value for them; they appear to have gained an understanding of the relevance of mathematics to the practising engineer which they did not previously have, even though all students work part-time in engineering or trades environments. It appears that either the students do not engage with mathematics in work or that the mathematics surrounding these students in their work environment is invisible to them. For example, one student states 'I didn't realise how much maths was to be involved in doing a job like this because usually someone else does it.' It is also likely that workplace mathematics appears distinctly different to mathematics in engineering education (Gainsburg, 2007). It is noted that no student chose to investigate mathematical thinking (tacit mathematics) that has greater relevance compared to curriculum mathematics in engineering practice (Goold & Devitt, 2013). Only one student sought the assistance of an engineer from his workplace, the engineer gave the student a mathematical problem to solve.

It is apparent that students' new learning about mathematics in engineering practice motivates them to engage more with mathematics that is important to them. Students have acquired a sense of wanting to learn mathematics; they now see themselves as learners preparing for their future careers. Students' responses include:

- 'The one major finding I got was when I looked up potential career opportunities in environmental engineering . . . in all of the job opportunities in environmental engineering, statistics and probability are fundamental in gathering and presenting your data'
- 'Before I began the assignment I felt like it could be a waste of time but on finishing the report I've changed my mind . . . . My understanding of algebra has improved and so has my respect for the subject . . . I can now see the relevance of algebra and its close ties to areas of engineering I will be involved with'
- 'This assignment certainly opened my eyes and helped to understand things a bit better'
- 'Having done this report I was surprised just how essential statistics are to successful engineering . . . it was good to see that some of the course topics will be so important in a future engineering career'
- 'This assignment changed my thinking about mathematics because I can now see how engineers can use it in different ways . . . I can see how engineers use mathematics to connect to their knowledge . . . I can now see a clearer picture of what we are doing now and in the future'
- 'This assignment was not my most favourite part of maths but before I didn't realise how important maths is especially in the field of engineering practice . . . I have learned a lot from doing the assignment'
- 'I found this assignment interesting and it gives me a feeling for what I can expect after college'

7. Concluding discussion

The findings in this study highlight the challenges of mathematics education, whereby engineering students who have negative feelings about mathematics engage in repetitive learning of mathematics often at the expense of understanding. Students' goals are to learn sufficient mathematics to pass their examinations and they show no desire to learn mathematics outside the curriculum. Students also demonstrate low mathematics task value; they are reluctant to investigate and write about useful mathematics (e.g. interesting mathematics or applications of mathematics in engineering practice) or to discuss mathematics generally. They are uncomfortable with the ambiguity of an investigative approach; they prefer the certainty of following set rules in order to achieve the 'correct answer'.

This study illustrates the impact of students' investigations' of mathematics usage in engineering practice on their motivation to learn mathematics. It appears that students' current work environment does not generate the same awareness or sense of importance of mathematics in engineering practice compared to this study. Possible reasons for this include: lack of confidence and a corresponding avoidance of mathematics, not recognizing the hidden mathematics (tacit as opposed to explicit) or a reluctance to engage in mathematics communication. However, having completed the exercise, students show increased mathematics task value; in particular they now see how a variety of mathematics topics and applications can benefit engineers' work. This in turn generates increased student interest in mathematics, and particularly in mathematics that is useful to students' future careers in engineering practice. The students' enhanced relationships with mathematics are attributable to the students' exploration, negotiation and ownership of knowledge resulting from their investigations (Black *et al.*, 2009).

It is reported that graduate engineers' difficulty in communicating mathematics is a significant weakness of engineering education (Goold, 2014). This study introduces students to the concept of communicating mathematics and its relevance. In the absence of communication the relevance and context of the mathematics is lost, similarly the real-world benefit of the mathematics is lost.

It is also noted that one student who found mathematics difficult to 'self-learn', discovered, from the exercise, that mathematics learning can take place outside the classroom given the availability of a variety of mathematics learning resources on-line. This reinforces the idea that experienced learners seek and engage life experiences with a learning attitude and they believe in their ability to learn.

The study illustrates the positive changes in students' mathematics attitudes arising from their insight into engineering practice. The study also illustrates that feelings about mathematics are an important factor in mathematics learning and that mathematics communications is part of engineers' work. It is anticipated that positioning this type of assignment earlier in the curriculum may have a greater benefit given students' increased mathematics learning value arising from this study. The study also provides evidence for a requirement to better match the mathematics in engineering education with the mathematics required in engineering practice. While engineering education mostly imparts knowledge, the role of practising engineers is 'to frame the problem correctly and maybe express it in maths, then they have to solve it and then they have to interpret the solution and communicate that to the decision maker' (Goold & Devitt, 2012).

It is concluded that engaging students in tasks that do not solely rely on the 'precise' rules of mathematics and the 'correct answer' but instead on the usefulness of mathematics improves students' relationships with mathematics and their motivation to engage with mathematics generally.

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Appendix A. Student assignment

A.1 Technical mathematics 3

A.1.1 Mathematics in engineering practice assignment (20%)

- Select an aspect of mathematics you have studied in IT Tallaght and, using whatever resources available to you, investigate how professional engineers use this mathematics in engineering practice.

A.1.2 Communication

- Document your investigative approach, sources of information and findings. Write a report (5 pages minimum) describing your work. Your report should include the following headings:
  - Introduction
    - Describe the particular area of mathematics you chose and state what factors impacted your choice.
  - Methodology
    - State how you planned your work; what resources did you use to investigate your mathematics topic?
  - Findings
    - What did you find?
    - Did the assignment change your thinking about mathematics?
  - Conclusion
    - What did you learn? What did you feel about the task (before, during and after)?
    - Create an A3 poster that illustrates your findings and give a 5 minute presentation in class.

Appendix B. 'Before' survey instrument

B.1 Instructions

I am looking for a description of your feelings about mathematics; there are no unique correct answers. Please answer **all** questions by writing your answers in the spaces provided.

(1) Briefly describe how you fell about mathematics generally.
(2) Are you confident dealing with mathematics? **Why/why not?**
(3) What mathematics topics have been particularly difficult for you?
(4) What learning strategy helped you overcome a mathematics difficulty you encountered?
(5) What mathematics topics have been particularly easy for you?
(6) What mathematics teaching/learning methods work best for you?
(7) How important is mathematics in your life generally? **Why / why not?**
(8) Do you like mathematics? **Why / why not?**
(9) Do you think that the mathematics topics in your current mathematics curriculum are necessary for your engineering course? **Why / why not?**
(10) Could engineering mathematics be improved? **How?**
(11) What role do you think mathematics will play in your future career?
(12) Describe any mathematics engagement/discussions you have outside lectures.
(13) Who or what has been the biggest impact on your relationship with mathematics?
(14) How do you think young people's feelings about mathematics could be improved?

Appendix C. 'After' survey instrument

C.1 Instructions

I am looking for a description of your feelings about mathematics; there are no unique correct answers. Please answer **all** questions by writing your answers in the spaces provided.

(1) Did you like the ''Mathematics in Engineering Practice'' assignment? **Why / why not?**
(2) **What** did you learn from the assignment?
(3) Did the assignment change your **feelings** about mathematics? **In what way?**
(4) Having completed the assignment, do you think that engineering education should put more emphasis on the **social aspect of mathematics** for example (i) communicating mathematics and (ii) identifying applications of mathematics in engineering practice?
(5) Do you think that open-ended mathematics assignments, such as this one, create more positive identifications (for example, improve students' relationships) with mathematics compared to traditional learning of mathematics? **Why?**
(6) Do you have any additional comments?

Dr. Eileen Goold lectures in the Department of Electronic Engineering at the Institute of Technology Tallaght, Dublin. Eileen is a Chartered Engineer and she has considerable experience in both engineering education and practice. Her main research interests include mathematics used in engineering practice and enhancing teaching and learning in engineering education.