International Journal of Mathematical Education in Science and Technology, Vol. 00, No. 00, 7 May 2011, 1–12

RESEARCH ARTICLE

Students' perceptions of the relevance of mathematics in engineering

Jennifer Flegg[a,b], Dann Mallet[b*] and Mandy Lupton[c]

[a]*Nuffield Department of Clinical Medicine, University of Oxford, United Kingdom*; [b]*Discipline of Mathematical Sciences, Faculty of Science and Technology, Queensland University of Technology, Brisbane, Australia*; [c]*School of Cultural and Language Studies, Faculty of Education, Queensland University of Technology, Brisbane, Australia*
(*Received 00 Month 200x; final version received 00 Month 200x*)

In this paper, we report on the findings of an exploratory study into the experience of students as they learn first year engineering mathematics. Here we define engineering as the application of mathematics and sciences to the building and design of projects for the use of society [1]. Qualitative and quantitative data on students' views of the relevance of their mathematics study to their engineering studies and future careers in engineering was collected. The students described using a range of mathematics techniques (mathematics skills developed, mathematics concepts applied to engineering and skills developed relevant for engineering) for various usages (as a subject of study, a tool for other subjects or a tool for real world problems). We found a number of themes relating to the design of mathematics engineering curriculum emerged from the data. These included the relevance of mathematics within different engineering majors, the relevance of mathematics to future studies, the relevance of learning mathematical rigour, and the effectiveness of problem solving tasks in conveying the relevance of mathematics more effectively than other forms of assessment. We make recommendations for the design of engineering mathematics curriculum based on our findings.

Keywords: engineering, mathematics, curriculum, higher education, undergraduate

1. Introduction

Engineering can be defined as the "application of mathematics and sciences to the building and design of projects for the use of society" [1]. Mathematics provides training in rational thinking as well as tools for undertaking analysis to obtain information about systems [2]. However, there are problems associated with the role of mathematics in engineering, in particular related to attracting and retaining students in engineering degrees. For instance, in recent years, the popularity of engineering degrees among undergraduates has declined [3, 4], thought to be due to a lack of understanding as to what engineering involves [3] and an insufficient mathematical preparedness [3–7]. Internationally, the mathematical skills of incoming students to quantitative courses appears to have dropped [5, 6]. Moreover, very high attrition rates of up to 50% are experienced in some engineering courses, due to difficulties encountered in the mathematical content of the degree [8–11]. Suggestions have been made to provide a gentler introduction to studying

*Corresponding author. Email: dg.mallet@qut.edu.au. GPO Box 2434, Brisbane 4001, Australia.

ISSN: 1045-1129 print/ISSN 1029-0346 online

DOI: 10.1080/1045112YYxxxxxxxx
http://www.informaworld.com

mathematics at university by reviewing when and how much mathematical content is in the curriculum [5, 9]. We would argue that the recognition of the role of mathematics in engineering is crucial for its relevance to be perceived by students and hence to ensure that students take steps to overcome any mathematical difficulties they encounter, promoting progression through the engineering degree. This paper reports on a small scale, mixed methods study investigating first year students' views of the relevance of mathematics to their engineering degree and future career.

1.1. *The relationship of mathematics to engineering*

The importance of mathematicians to engineering is recognised by organisations such as the Engineering Council [7]. It has been argued that the competence of an engineer rests, to a large degree in their mathematical training [12]. This training is perceived differently by employers. For instance, some employers of engineering graduates look for students to have a holistic awareness of mathematics while others are keen that mathematics should instil a rigorous development of arguments [13].

With regard to how mathematics should be taught in engineering degrees, some academics support the need for mathematical rigour/formality [13] while others argue against it [12, 14]. Barry et al. support time being spent on mathematical modelling problems that relate to engineering as well as addressing mathematical communication skills, while Noskov argues for the student to gain an appreciation for "how mathematical concepts, theorems, and methods relate to the student's future profession". However care should be taken, as others argue that the student perception of mathematics may be largely associated with repeated and explicit use of rules and formulae and that this may obscure the role that thinking mathematically plays in engineering practices [15].

The environment in which students are exposed to mathematical ideas has been argued to play a large role in how they engage in mathematical thinking [16]. Without the explicit connection between theory and practice, the mathematical content of engineering programs may not be seen by students as relevant. In general, the literature strongly supports the use of problem based learning strategies where students are required to engage in learning tasks that are relevant to profession practice [17–20].

Mathematics departments often have responsibility for teaching mathematics to engineering students. This may lead to the situation where engineering departments have little idea of what mathematical content is presented to their students in the standard prerequisite mathematics units [21]. Furthermore, there seems to be no consistent, research-informed, view of how, what, when and by whom mathematics should be taught to engineering students [7, 13, 21–23]. It could be argued that in order for engineering students to see the relevance of mathematics that it would be better for engineering departments to integrate mathematics into engineering units rather than having separate mathematics subjects. On the other hand, others would argue that experts, that is mathematicians, should be responsible for teaching mathematics. A confounding issue is that many mathematics departments depend heavily on income from service teaching and would be reluctant to hand over teaching of the mathematics component of engineering courses [7, 13, 23, 24].

It is in the interests of both mathematics and engineering academics to understand how students view the relevance of mathematics to engineering. This understanding can then inform curriculum design to engage students in applying mathematics to engineering.

1.2. *Engineering mathematics teaching methods and curriculum design*

Contemporary curriculum theorists argue that the connection between theory and practice can be developed using authentic teaching and learning approaches [17]. Henderson et al. reviewed the major teaching approaches typically adopted within Australian universities by mathematics departments who service teach into engineering degrees. They found that the four most common methods were problem-based learning, multi-disciplinary approach, computer based methods and strategies that specifically address variability in the mathematically preparedness of incoming students [25]. The authors comment that it is "difficult to engage, educate to a common level and demonstrate the relevance of maths to an increasingly diverse student body".

Within engineering curricula, a strong emphasis is placed on problem solving skills whereby students are required to formulate a problem, carry out mathematical analysis and interpret the results within an engineering context [26]. Cardella argues that engineering students should be taught to mathematically model, check for uncertainty in the mathematical models they design, and to check for errors when using mathematical tools [16]. There is also support for an increased focus on the use of software packages and data analysis tools by practicing engineers, which are yet to be reflected in mathematical courses [4, 25]. However, this perceived lack of alignment was viewed differently by engineering students who rated the use of mathematical software as least useful among the mathematical skills taught to them [4].

If engineering students do not see the importance of mathematics to their studies or their future professional practice, then regardless of what approach to curriculum is employed, student interest is likely to be low. Booth suggested that there are three main ways that engineering students experience the process of learning mathematics: 1) as a subject of study, 2) as a tool for other subjects of study and 3) as a tool for dealing with real world problems [27]. Thus, in this paper we investigate how students view the relevance of mathematics to engineering and how they experience the process of learning mathematics from these three perspectives.

2. Context

This study focuses on how engineering students viewed the relevance of the mathematical ideas they learned in a first year engineering mathematics course at an Australian university. The aim of the course was for students to apply mathematical techniques to engineering problems. The students' ability to apply their knowledge was assessed using quizzes and exams. In addition, a problem solving assignment allowed students to tackle detailed, unseen questions that required them to use other resources besides those provided for them as part of the course. The assignment was designed to extend students' thinking in three major topics covered during the semester:

(1) Multiple integrals – students were asked to investigate the use of multiple integrals to find the centre of gravity, an important concept in engineering projects.
(2) Vector calculus – students were required to solve a much generalised projectile motion question to obtain relationships between angle of projection and maximum distance covered by the projectile.
(3) Partial differential equations – students were required to derive the heat equation in spherical coordinates from the general heat equation. They are also asked to verify that a given function is a solution to the equation.

There were 193 students that completed course.

3. Research methods

The research reported here from one first year engineering mathematics course should be seen as exploratory. Further research would naturally be required in order to make solid general conclusions regarding how engineering students see the relevance of mathematics to their future studies and careers. The conclusions in this study are of relevance to the Australian context and to other similar university contexts.

Both qualitative and quantitative data were collected. Three data collection tools were administered towards the end of semester. First, 27 students (of the 193 students who completed the course) provided short written answers anonymously to the following questions:

(1) The skills I have developed through taking mathematics units at university include:
(2) The ways in which the skills that I have developed through learning mathematics are relevant to engineering are:
(3) In general, I would say that mathematical concepts are applied to engineering in the following ways:

Second, individual in depth interviews were conducted with five students. Students were asked questions related to how they saw the relevance of mathematics to their future study and career. The interview questions included the following:

(1) What knowledge and skills do you feel are assumed when you come into the engineering degree?
(2) How do you see the relevance of learning mathematics in an engineering degree?
(3) How do you think you will use what you've learned in mathematics units in the future?
(4) What would you say that you gain out of seeing and doing formal mathematics?

Last, 34 students (of the 193 students who finished the course) completed a questionnaire asking them to rate how strongly they agreed (strongly agree, agree, neutral, disagree or strongly disagree) with statements that related to the research question. The full questionnaire is presented in Table 1.

3.1. *Data analysis*

The qualitative (interview and short written response) data were analysed in a number of ways. One analysis method consisted of looking for levels of sophistication in the way students saw (or didn't see) the relevance of mathematics to engineering. These views were drawn from Booth [27] where mathematics is seen:

(1) as a subject of study;
(2) as a tool for other subjects of study (both for study and in the world at large);
(3) as a tool for dealing with real world problems.

If a student mentioned the relevance of learning mathematics as an end in itself (i.e., to pass the exam), we coded this response as the first view. If the student mentioned using mathematics for other subjects such as physics we coded their

Table 1. The student questionnaire.

Statement	SA	A	N	D	SD
I can see how the mathematics skills that I am currently developing will be useful in an engineering career.					
Being integrated with other first year mathematics students helps me to get a better understanding of the uses of mathematics as a whole rather than just in the engineering fields.					
The ways of thinking being taught to me as part of this unit will remain with me long after I graduate.					
I feel that this unit teaches me how to formulate and solve problems that are directly related to engineering.					
This unit exposes me to ideas which I know I will need later on in my engineering degree.					
I see being able to communicate effectively using mathematical arguments as an important skill to have.					
The formal and rigorous aspects of mathematics that I seen in this unit are important for my future engineering career.					
For me, I only want to learn what I feel is likely to be assessed.					
At some stage during my degree I have been so overwhelmed by mathematical content that I have considered withdrawing from my engineering degree.					

response as the second view. If they mentioned using mathematics to understand more about professional practice in engineering, we coded their response as the third view. A further analysis involved teasing out the concrete aspects that students mentioned as:

(1) mathematical skills developed;
(2) mathematical concepts applied to engineering;
(3) skills developed relevant to engineering.

Where we have reported the results from the anonymous short written questions we have distinguished the students as S1, S2 and so on. Where we have reported the results from the interviews we have distinguished the students as S1 interview and so on.

Furthermore, we found some themes emerging from the data that provided an insight in mathematics for engineering curriculum design. We have reported these as themes below in the discussion section.

4. Results

The results indicated that there was a range of understanding of the relevance of mathematics to engineering, and the perception of mathematics per se.

4.1. *Relevance of mathematics to engineering*

The majority of students either agreed or strongly agreed that mathematics is relevant to their future career and study (see Table 2). The highest ratings were for the skills being taught in the course (ways of thinking 82%, ideas 79%, mathematical skills 76%, communicating using mathematical arguments 94%). The lowest agreement (59%) was regarding the success of the course in teaching students how to formulate and solve problems that are directly related to engineering.

It was apparent from the interviews that students varied in the levels in which they perceived the relevance of studying mathematics to engineering. Some students did not see the relevance, while some saw the relevance for their university study of engineering but did not necessarily have an awareness of using mathematics in the industry. Others were able to see the relevance to professional practice.

Table 2. The results of the questionnaire that related to relevance of mathematics to future career and study.

Question	D or SD	N	A or SA
I can see how the mathematics skills that I am currently developing will be useful in an engineering career.	1	6	27
The ways of thinking being taught to me as part of this unit will remain with me long after I graduate.	0	6	28
I feel that this unit teaches me how to formulate and solve problems that are directly related to engineering.	4	10	20
This unit exposes me to ideas which I know I will need later on in my engineering degree.	2	6	26
I see being able to communicate effectively using mathematical arguments as an important skill to have.	0	2	32

For example, student 1 struggled to find the practical application of mathematics to engineering and made no mention of how it might relate to engineering subjects or his future career. However, he was able to see the relationship between mathematics to his physics subjects:

> [I don't see the relevance] all that much. As with all maths, I just sometimes don't see the practical applications. I have seen some, which was refreshing, more than at high school at least. There are points where the maths that I do in the maths course which actually helps with the other units. Knowing the formula that they use in physics was gained by integration and derivation. So if I were to not remember the formula, I could find it myself. So it's really finding out how to find out what you want to do. (S1 interview)

By contrast, students 2-5 were able to relate their maths learning to engineering with varying levels of sophistication. It is clear from the responses below that several students have formed an identity in relation to a field of engineering, and they are able to relate the mathematics they need to the course that related to the field. For instance, student 2 linked his study of mathematics to engineering subjects: "I'm doing the civil calculations for our groups ... and there is a lot of maths involved."

> Well, I'm definitely going to [do] civil and I'm working at structural analysis in crane. Lots of truss analysis and things like that and for design and another subject, it's quite a bit of calculations. I'm doing the civil calculations for our groups on it and there is a lot of maths involved. There is a lot of integration, differentiation, calculus I do say, but it's also general knowledge of a lot of forces calculating things like that. (S2 interview)

> It depends. For example, since mechatronics is a combination of mechanical, electronic and software, so when it comes to mechanical stuff, there will be problems that we need to deal with like calculation. For example, calculation of the forces, reaction forces. Maybe sometimes we might be going to more advanced sort of stuff? Where we require vectors and matrices, we actually do complex calculation. (S4 interview)

Other students could relate mathematics concepts to engineering, but did not specify a particular field. For instance, student 3 mentioned how mathematics was relevant in a university setting, specifically in an engineering control subject.

> Oh, yeah, math is important; it is related with my interest about the control, because in a control subject that I have learnt in my Indonesian University it depends on, very important mathematics, especially for Laplace transform. I need some integral form, derivative form and combining them. (S3 interview)

Student 4 was aware that there might be applications outside of a university setting: "when it comes to mechanical stuff, there will be problems that we need to deal with like calculation", however it is student 5 who makes explicit how she thinks mathematics will be used in her future career: "I think yeah that I would need derivation. It's also good with reasoning. So when you have to explain to your boss this is how I came to it". It should be noted that student 5 was the only student who had completed a significant amount of work experience with an engineering company.

> If you get the whole concept of derivation of formulas, it's good because when you're setting up programs or modelling, that's what they call them, modelling on Excel, if you know what the whole concept of derivation you can actually derive your own formula from a bunch of other formulas to suit whatever's required in the project, whatever value that you need to come to or some analysis. So I think yeah that I would need derivation. It's also good with reasoning. So when you have to explain to your boss this is how I came to it. It's always good to have like whenever you have a project you have the software and you also have your design working pad. It's good to have those preliminary calculations and have it filed again because if something goes wrong you go into that file, grab out those calculations, and from those derivation techniques you can reason out why you've come to that value and why the structure has failed or why do you think it's not your fault. (S5 interview)

4.2. *Perception of mathematics*

The three views of mathematics: 1) as a subject of study, 2) as a tool for other subjects of study (both for study and in the world at large), and 3) as a tool for dealing with real world problems were evident in all of the data collected. In this section, we present our analysis of the short written answers in relation to the three views (see Table 3). The students described a range of techniques (mathematics skills developed, mathematics concepts applied to engineering and skills developed relevant for engineering) for various usage (as a subject of study, a tool for other subjects or a tool for real world problems).

Students mentioned mathematics skills such as integration and differentiation (as a subject of study), higher level calculus (as a tool for other subjects) and deriving formulae (as a tool for real world problems). Comment was also made as to mathematical concepts applied to engineering at each level of use such as problem solving, calculation of engineering quantities and modelling outputs of equipment. Lastly, skills that were relevant to engineering were mentioned including calculating areas, analysing electrical currents and learning multiple ways to approach a problem.

4.3. *Discussion of curriculum issues*

There are a number of aspects relating to curriculum issues raised by students in this study. We have presented these below in themes and discussed them in relation to the literature. These themes are: 1) the difference in perceived importance of mathematics within different engineering majors, 2) the difficulty in seeing the relevance of mathematics to future studies, 3) learning through problem solving tasks 4) the relevance of formal/rigourous mathematics and 5) assessment in engineering mathematics. We present these themes with a view to providing suggestions and considerations for curriculum designers.

4.3.1. Theme 1: Relevance of mathematics within different engineering majors

A difference in student perception of mathematics was found between engineering majors by Coupland et al., who suggested that mechanical engineering students appear to see the relevance of mathematics more than the other engineering fields [4]. This is also noted in other research [2]. However, in this study we found several

Table 3. Analysis of short written responses in relation to the three views of mathematics.

	Mathematics skills developed	**Mathematics concepts applied to engineering**	**Skills developed relevant to engineering**
Subject of study	Rules of integration and differentiation. Multi-differentiation. (S1) Lots of integration and differentiation. Finding areas by integration. Lots of theory. Multivariable calculus. (S10) Integration, differentiation, finding areas and volumes, critical points, multivariable calculus. (S11)	Solving problems. (S12)	Finding areas under graphs and stuff. (S1) The emphasis of practicing questions to become good at them. (S14)
Tool for other subjects of study	Improved knowledge and skills of calculus. Problem solving. (S4) Higher level calculus skills and understanding. Better understanding of vectors and other important concepts relative to engineering. Improved problem solving skills. (S13)	We need them because a lot of engineering is based on maths. Like finding forces and stuff. (S1) Working out electrical information such as power in alternating current and other electrical concept use integration and differentiation. (S3)	Finding forces in members in different truss designs. Good use in electrical engineering unit I am taking. (S17) Good for the electrical engineering subject with DC and AC current. Helpful when finding forces in a truss structure. (S16) By applying the maths concepts to engineering problems. (S2) Electrical things. Physics things are only very simple maths. (S9)
Tool for dealing with real world problems	I can derive something in a formula instead of remembering a lot of formulas. (S20)	Density calculations, centre of gravity, heat, pressure, projectile motion. (S2) Analysing outputs of equipment and designs. (S8) Modelling real life used in computer programs. (S18)	Engineers need several ways to solve/approach a problem. (S13) Calculation of velocity, distance (range) and time taken for the object to reach maximum height and ground level. When designing a structure we need to know the centre of mass is order to design a system that would distribute the load and ensure the stability in the structure. (S24)

instances where students mentioned electrical engineering concepts with respect to the relevance of mathematics:

> Power in alternating current and other electrical concepts. (S6):
>
> Some engineers need maths, others don't. For electrical engineering. I want to do civil though, so I feel its help for me is more to do with algebra. (S14)
>
> DC and AC current. (S16)
>
> I think 80% of Math is useful for Electrical Engineering" (S3 interview)

Such observations would indicate that it is important to make the links to other engineering fields more explicit.

4.3.2. Theme 2: Relevance of mathematics to future studies

In previous research it has been found that first year engineering students cannot yet appreciate the connection between their experiences in mathematics and their later engineering subjects [4]. This finding was supported in our study, for example:

> It is not easy to answer as first years will not know (S3)

> I don't see how most of the skills I have learnt apply. (S3)

> I really don't know right now. I guess you never really know until you need it. (S10)

However, as reported in Table 2, 76% of students who responded to the student questionnaire claimed that the mathematical unit they were currently studying had exposed them to ideas they would need later in their degree. Furthermore, 82% said that the ways of thinking would remain with them after they had graduated and 79% that the ideas will be useful in an engineering career. On the other hand, only 59% of students thought that the unit exposed them to real engineering problems.

Sazhin states that "mathematics is a language for expressing physical, chemical and engineering laws" [28]. Therefore, we would argue that regardless of the type of engineering a student is studying (e.g. mechanical, civil, electrical), it is essential that mathematics be a fundamental component of their degree program. Typically, mathematics units comprise 25% of the first year subjects in an engineering degree [25]. However, Mustoe notes that it is problematic to expose engineering students to mathematical rigour in the first year of university before the student has been given a sense of where the techniques apply [7]. Furthermore, it is possible that students could forget the content of first year units by the time they get to the final years of their degree [20]. We found in our study that students could see the importance of studying mathematics in first year and beyond.

> Yeah, it has to be in the first year I think because math is the foundation of engineering. Because before we studied engineering, because the lecturing in engineering, they don't have to teach about the foundation of math. (S3 interview)

> I think it should be both...Yeah, so when we do the math, we can see the application of the unit. When, in the same semester, we can see it, actually, how it actually works in the unit. We need a topic. (S4 interview)

> I think they should be in the first year. The whole concept of center of gravity and all that projectile motion. Because in the second year units then the students will diverse into their own schools and they will go into depth on the designs. That whole concept of center of gravity, that's just the basics. I think that's just a basic for the whole calculation thing and then when they go into their own separate schools then they go in depth. (S5 interview)

However, we cannot take for granted that engineering students see the relevance for themselves, especially when they are in their first year of study. We would argue that it is important to emphasise the relevance at every opportunity. Furthermore, relevance should be embedded in curricula by designing mathematical subjects in collaboration with engineering staff [2, 16].

4.3.3. Theme 3: Students learn applications better through problem solving tasks

It is likely that the most effective way to teach mathematics to engineering students is to present mathematics in terms of concepts that students already understand: physical, chemical and engineering laws. As Sazhin states, engineering students "learn physical concepts much easier than mathematical concepts" [28]. An appropriate balance should be made between the abstract understanding of mathematical concepts that the students will need in their future careers and numerical, practical examples that the students can more easily relate to.

It would follow, then, that mathematics departments must work closely with engineering departments to ensure that the mathematics relates directly to what the students are likely to need later in their degree, and in industry [7]. Cardella notes that the problem solving skills that are taught to engineering students in mathematics subjects might be used later on in their degree and/or career [16].

We found that the applications of mathematics that had remained with the students were typically the ones from problem-solving tasks, rather than the numerous ones discussed during the lectures. For example the students mentioned:

> Centre of gravity, heat, pressure, projectile motion. (S2)

> Density, mass and volume. Centre of gravity. Vectors and movement. (S23)

> Calculation of velocity and distance, centre of gravity, projectile motion. (S24)

Furthermore, in the short written questions the students commonly mentioned "problem solving skills" as what they had learnt in mathematics subjects (Students 2, 4, 5, 12, 13, 15, 21). The student interviews revealed a similar view of the importance of problem solving skills:

> Center of gravity because you need to know the center of gravity when you are designing for structures, buildings, and all that stuff. Projectile motion as well. (S5 interview)

> The problem solving task is more useful [than examinations]. (S3 interview)

These findings are consistent with the idea that mathematics can be used as a tool for other subjects of study (both for study and in the world at large), and as a tool for dealing with real world problems as reported earlier in this paper.

4.3.4. Theme 4: Relevance of learning mathematical rigour/formality

The role of mathematical rigour in engineering courses is highly debated [12–14]. The engineering students in this study were learning mathematics from mathematicians in a unit along side undergraduate mathematics students. However, as Humphrey Davies argues, we need to keep in mind that it is possible that engineering students are not "natural mathematicians", therefore it is important to keep the formal mathematical aspects to a reasonable level [29]. It was apparent from the questionnaire that students saw the value of learning mathematical rigour in this context. For instance, 68% of students thought that the rigorous aspects of mathematics would be important to them in the future. Furthermore, 44% of students supported being integrated with the undergraduate mathematics students. Students commented that the formal side of mathematics they were shown as part of their degree was useful:

> Yes, sort of, because math actually makes your head start to think quickly. The more of this you do it, the more perfect calculation you will be getting. (S4 interview)

> If you know what the whole concept of derivation you can actually derive your own formula from a bunch of other formulas to suit whatever's required in the project, whatever value that you need to come to or some analysis. (S5 interview)

These findings seem to support the practice of using mathematicians to teach engineering students alongside mathematics students. However, as mentioned above, mathematics departments and engineering departments need to work closely together to reinforce the relevance of learning mathematical rigour.

4.3.5. Theme 5: Assessment in mathematics for engineering subjects

In mathematics subjects the traditional assessment is a heavily weighted final examination. However, this may not be the most appropriate assessment for engineering mathematics subjects [25, 28]. The questionnaire revealed that over 30% of students had been so overwhelmed with the mathematical parts of their degree that they had considered withdrawing from their degree. This might be related to the format of assessment in engineering mathematics subjects. For instance, student 18 commented that "between [my other mathematics unit] and this unit, I have lost all enjoyment of doing maths. This is largely due to the difficulty of the final exam". However the interviews revealed a mixed response to the high percentage exam (60%):

> I think the exam is a good thing to be about half, half the total assessment (S2 interview)
>
> Well, because, problem-solving task is, we can open the books, open the sources, but in examination we don't, because maybe we are just provided with the formula, but 60% are from our brain, where we have learned from (S3 interview)
>
> Probably exam [is better]. (S4 interview)
>
> I think it's good. I think yeah, exams, to my understanding, it keeps up the [quality] of students. (S5 interview)

4.4. *Recommendations for mathematics engineering curricula*

Mathematics is a vital part of any engineering degree [28]. It is evident from this study that students generally see the relevance of mathematics to engineering. Furthermore, they are able to see mathematics as 1) a subject of study, 2) as a tool for other subjects of study (both for study and in the world at large), and 3) as a tool for dealing with real world problems. We would argue that mathematics engineering curricula should be designed to specifically target using mathematics as a tool for dealing with real world problems.

The literature strongly supports the use of problem-based learning [18–20, 30]. The benefits of using problem based learning in engineering mathematics are that the student can be expected to deal with a level of formality which they might not be familiar with and that would not be appropriate to assess under examination conditions. Furthermore, the investigation of a complex mathematical problem can be self-directed.

A unified approach between mathematics and engineering departments is crucial if we are to have any hope of influencing how engineering students see the use of mathematics in their degrees and future careers [2, 4, 16, 21]. In fact, there is often significant differences in the mathematical terminology and notation adopted by engineering and mathematics lecturers [4, 21]. In this case, there is little wonder why students often fail to see the relevance of what they are taught in mathematics units.

Thus, we recommend that for students to see the relevance of mathematics to engineering there should be close collaboration between mathematics and engineering departments in designing curricula based around problem solving tasks.

Acknowledgements

JF would like to thank the Queensland University of Technology for a Vice-Chancellor's bursary. We would also like to thank the students who participated in the study.

References

[1] M. Kirschenman, , and B. Brenner, *Education for Civil Engineering: A Profession of Practice*, Leadership and Management in Engineering 10 (2010), p. 54.
[2] L. Mustoe and D. Walker, *The Teaching of Mathematics for Engineers*, International Journal of Mathematical Education in Science and Technology 1(4) (1970), pp. 389–401.
[3] E. Bowen, J. Prior, S. Lloyd, and L. Newman-Ford, *Engineering more engineers-bridging the mathematics and careers advice gap*, Engineering Education: Journal of the Higher Education Academy Engineering Subject Centre 2 (2008), p. 23.
[4] M. Coupland, A. Gardner, and G. Carmody, *Mathematics for Engineering Education: What Students Say*, (2008).
[5] T. Hawkes and M. Savage, *Conference Report*, in *Measuring the Mathematics Problem*, 1999.
[6] A. Heck and L. Van Gastel, *Mathematics on the threshold*, International Journal Of Mathematical Education in Science and Technology 37 (2006), pp. 925–945.
[7] L. Mustoe, *The mathematics background of undergraduate engineers*, International Journal of Electrical Engineering Education 39 (2002), pp. 192–200.
[8] M. Besterfield-Sacre, C. Atman, and L. Shuman, *Characteristics of Freshman Engineering Students: Models for Determing Student Attrition in Engineering*, Journal of Engineering Education 86 (1997), pp. 139–150.
[9] N.W. Klingbeil, R.E. Mercer, K.S. Rattan, M.L. Raymer, and D.B. Reynolds, *Redefining engineering mathematics education at Wright State University*, in Proceedings 2006 ASEE Annual Conference & Exposition, 2006.
[10] L. Bernold, J. Spurlin, and C. Anson, *Understanding our students: A longitudinal-study of success and failure in engineering with implications for increased retention*, Journal of Engineering Education 96 (2007), p. 263.
[11] H. MacGillivray and R. Cuthbert, *Investigating weaknesses in the underpinning mathematical confidence of first year engineering students*, in *Proc. Australasian Engineering Education Conference*, 2003, pp. 358–368.
[12] M.V. Noskov and V.A. Shershneva, *The Mathematics Education of an Engineer: Traditions and Innovations*, Russian Education & Society 49 (2007), pp. 70–84.
[13] P. Kent and R. Noss, *Mathematics in the university education of engineers: a report to the Ove Arup Foundation*, (2003).
[14] M.D.J. Barry and N.C. Steele, *A core curriculum in mathematics for the European engineer: an overview*, International Journal of Mathematical Education in Science and Technology 24 (1993), pp. 223–229.
[15] K. Devlin, *The real reason why software engineers need math*, Commun. ACM 44 (2001), pp. 21–22.
[16] M.E. Cardella, *Which mathematics should we teach engineering students? An empirically grounded case for a broad notion of mathematical thinking*, Teaching Mathematics and its Applications 27 (2008), p. 150.
[17] A. Herrington and J. Herrington, *What is an authentic learning environment*, Authentic learning environments in higher education (2006), pp. 1–13.
[18] M. Savin-Baden, *Disjunction as a form of troublesome knowledge in problem-based learning*, Overcoming barriers to student understanding: Threshold concepts and troublesome knowledge (2006), pp. 160–172.
[19] D.R. Sadler, *Transforming holistic assessment and grading into a vehicle for complex learning*, Assessment, learning and judgement in higher education (2009), pp. 1–19.
[20] G. Dall'Alba, *Investigating Preparation for Professional Practice*, Learning to be Professionals (2009), pp. 37–52.
[21] K. Willcox and G. Bounova, *Mathematics in engineering: Identifying, Enhancing and linking the implicit mathematics curriculum*, in Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition, 2004.
[22] E.W. Eisner and E. Vallance, *Five conceptions of curriculum: Their roots and implications for curriculum planning*, Conflicting conceptions of curriculum (1974), pp. 1–18.
[23] P. Edwards, J. Appleby, and J. Ahmad, *Engineering mathematics should be taught by engineers!*, (2001).
[24] L. Mustoe, Coming to terms with change: mathematics for engineering undergraduates; .
[25] S. Henderson and P. Broadbridge, *Mathematics for 21st Century Engineering Students*, in 2007 AaeE conference, 2007, pp. 9–13.
[26] M. Healey, *Linking research and teaching: exploring disciplinary spaces and the role of inquiry-based learning*, Reshaping the university: new relationships between research, scholarship and teaching (2005), p. 30.
[27] S. Booth, *Learning and teaching for understanding mathematics*, M. Demlova and D. Lawson, eds., 12th SEFI Maths Working Group Seminar, 2004, p. 12.
[28] S. Sazhin, *Teaching mathematics to engineering students*, International Journal of Engineering Education 14 (1998), pp. 145–152.
[29] M. Humphrey Davies, *The Requirements of the Engineering Department*, International Journal of Mathematical Education in Science and Technology 1 (1970), pp. 389–401.
[30] A. Herrington and J. Herrington *Authentic learning environments in higher education*, Information Science Pub, 2006.