Engineering mathematics—what do students think?

Leigh N. Wood[1]

(Received 31 July 2007; revised 4 January 2008)

Abstract

What do our students think of mathematics and how do we help prepare them for the workplace? This article reports results from an open-ended questionnaire with engineering students in five countries. We investigate how they conceive of mathematics and how they perceive their university study has prepared them for the workforce. The results show that students have different ideas of mathematics itself and how they will use it. Some view mathematics as a tool to be used in their professional lives, others think they will use the analytical and problem solving skills. There were also those who do not believe they will use mathematics at all—that computers will do it all for them. Since notions about future utility can influence engagement with learning, we as teachers need to proactively expand students' perceptions of the fundamental importance of mathematics to working as an engineer. I provide an example of an assessment task that will help students expand their ideas of how they will use mathematics in their careers.

See http://anziamj.austms.org.au/ojs/index.php/ANZIAMJ/article/view/360 for this article, Published April 15, 2008. ISSN 1446-8735

Contents

1 Introduction

Becoming an engineer is a journey from student to professional. There are many pieces of equipment that engineers may require, but mathematics is one accessory that is essential. Tertiary engineering courses usually include mathematics as a core subject at increasing levels of sophistication and application over the span of the degree. The end of the journey is likely to be interesting and rewarding, both in itself and in monetary terms. In Australia, graduate destination surveys show that engineering graduates who are seeking full-time employment are indeed able to find jobs, with good salaries as a bonus [1]. However, the future need for knowledge acquired at university within the workplace is often not clear to students. This not only applies to mathematics; the relevance of other parts of the curriculum to the role of an engineer may also be obscure. Indeed many students are unaware of what it would be like to work as an engineer, particularly during the early stages of their degree programs. Students' approaches to learning mathematics can be strongly influenced by their ideas about how the content and skills will be related to their professional life [10]. Understanding the requirements of being a professional, in terms of both capabilities and needs, can encourage deeper engagement with the subject matter. This article investigates students' ideas of how mathematics will be used in their future work, based on an international study across five countries and which included engineering students, and presents assessment tasks to broaden these views.

2 Background

For an engineer, mathematics provides more than a foundation of skills and techniques; it provides a language to describe their engineering world. This gives a wide field of choice, however, and the details need to be drawn in more precisely. The 1999, 2003 and 2005 Bologna declarations [3] included statements about the skills required for qualification across Europe in a range of professions, including engineering. Mathematics courses were considered in terms of both content and teaching methods, and the conclusion drawn was that advances needed to be made in reflecting technological change, which has influenced both the professional use of mathematics and potential teaching platforms. Although engineering is an area of creativity and innovation, recent articles on mathematics in the European Journal of Engineering Education [2, 7, 8, e.g.] tend to emphasise mathematics curriculum content rather than teaching methods or a more general idea of mathematics. Conversely, Kent and Noss [5] noted in their detailed UK case study of an engineering workplace that there was extensive use of mathematical modelling and mathematical concepts (higher order), and wide use of computing tools. They also found that graduates were insufficiently trained in explaining mathematical ideas. One European study that took account of student views was undertaken by Hult et al. [4], who found that many engineering courses did not connect well with the professional arena, and that students perceive their courses as being insufficient (see Table 1). They noted that:

> The discourse within the Engineering programme resembles

Table 1: Engineering students' experiences of their study program

	Freshmen	*Seniors*
Relevance	Low	Medium
Intensity	High	Low
Engagement	Medium	Medium
Visibility	Low	Medium
Professional Identity	Low	Medium

> the one in Political Science in that the notion is providing students with a basic knowledge from the outset of the program. The intensity is extremely high, students' professional identity is low as they fail to see the connection to the professional field as they engage in the tasks of the freshmen studies. This naturally also impacts on their engagement in the studies. The rationale behind this discourse is to prepare students for hard work, to enhance their capacity of learning new things rapidly. The relationship to teachers is vertical; students are anonymous to teachers in the freshmen part of the studies. The rationality is goal-oriented and emphasis on communication is non-existing [4, p.7].

Australian researchers have usually discussed engineering mathematics from the viewpoint of teaching mathematics from within a mathematics department to engineering students in a separate department. From 2000 to 2003 [13] there were around 20 studies reported on service teaching of mathematics, although Kirkup et al. [6] noted that such teaching tended to be approached in an ad hoc nature and there are difficulties in communicating across disciplinary boundaries. There were many studies on the introduction of technology such as Maple, and this trend continued from 2004 to 2007. In a study of mathematics graduates, Wood and Reid [11] found that in their workplaces they did not use some of the mathematics taught, but had to learn other mathematics; they needed more computing skills and techniques; and they needed better communication skills, particularly mathematical communication. Overall Australian studies have neglected the need for training engineering students in the realities of professional life, with a focus on the tools of the trade rather than on higher ideas and skills. All of these will be needed for the journey, and teaching and learning must reflect this. Other significant oversights include the investigation of students' own ideas about their education and future life, as well as the ideas of their lecturers. Moreover, there has been little investigation directly of graduates' reflections and actual workplaces—professional organisations and employers may be consulted, but the real experience of working as an engineer (and the mathematics actually required) has been ignored as an area of study. All of these are worthwhile trails to follow in order to better equip our engineering students for their future destination.

3 Conceptions of mathematics—the study

I am currently collaborating in a study that is focused on teasing out the ideas of students about what mathematics is and how they see mathematics will be used in their future. It is being run across five countries, including Australia, and here I discuss the results of an open-ended questionnaire that was administered to 1,182 mathematics students, of whom around 40% were in engineering programs. We have reported earlier on general ideas on what mathematics [9], which also included demographic data, and student views on future use in relation to performance [12]. We asked three open-ended questions:

- What is mathematics?
- What part do you think mathematics will play in your future study?
- What part do you think mathematics will play in your future career?

For this article I focus on the first and third of these: the conceptions of mathematics, and the perceptions of the role it may play within a career. The views about mathematics held by engineering students in our sample varied little from those who intended to specialise in other areas, except that they were more likely to think of mathematics as a tool rather than having a structure.

What is mathematics? The participants saw mathematics in many different ways and these quotes from their statements gives an indication of the general range:

- A waste of time.
- Calculation, computing. A useful tool for everybody.
- Mathematics is the way that we can explain the physical phenomena surrounding us.
- Conceptual thought and logical development of ideas.
- Mathematics is a way to approach life in an analytical manner as to support and formalise natural processes. In a sense it is a way to understand how life works.

Our approach to analysing the statements from the more than 1,000 participants involved our group of researchers reading all of them a few times, then developing groups of kinds of statements (categories). We held extensive discussions about the ways the statements could be grouped, then finally selected three main categories that incorporated not only individual statements but the body of statements as a whole: components/tools; structure (modelling/abstract concepts); life/career. A further two statements did not quite fit these categories and could be defined as new/creativity. These categories can be ranked from low (such as computation tools 52%; through structure 34%) to high (6%). Ten percent of responses could not be categorised.

What part do you think mathematics will play in your future career? The results we found for responses to this question highlight the uncertainty that many students feel about what it means to be a professional, and how the skills and knowledge they are acquiring at university will be applicable to the workplace. A surprising number gave answers that could be categorised as "No idea", or were very vague (such as "A small part", or "I'm not exactly sure"), while a significant proportion gave responses that dealt with mathematics as comprised of components and techniques. Although some of the students were doing mathematics as an adjunct to a seemingly unrelated course (such as international studies), most were heading for careers in which mathematics would play an intrinsic role. Here are some quotes from the participants:

- Am I a fortune teller?
- Not very big. Computer programs will do all the work and applications for you.
- It will help me do my job as an engineer in determining forces acting on or in an object in which I am designing.
- Studying mathematics has refined my problem solving skills and analytical skills. It has helped develop my intuition in dealing with numerical and other problems.
- I love maths and I think it will play substantial role in my career. It will help me solving engineering problems.

The uncertainty they felt reflects their responses to the question "What is mathematics", where few demonstrated higher level conceptions. However, they did at least have clear opinions about mathematics, whereas they showed a much greater level of haziness when asked about their future.

4 Implications for teaching

Students in our classrooms have very different ideas of what mathematics is; why they are learning it; and what they are going to do with it once they graduate. This in turn leads to different approaches to learning and different outcomes for each student. Final year students in our study displayed a greater degree of higher level conceptions, but still far too many saw mathematics, and its role in their future, in a simplistic way. Thus the nexus between university and professional work is shadowy indeed for many of our students. The connection between what is learnt in mathematics and working as an engineer is not clear, as one student put it: "It is a series of courses designed to make engineering more difficult than it is." Does this affect our teaching? It certainly should—as teachers we need to take into account the range of ideas that students hold and we must design learning experiences that motivate and extend students to move to higher level conceptions. There are various taxonomies for designing assignment and examination questions and for developing learning strategies, such as the one use by the calculus reform movement which looks at each mathematical situation from three viewpoints: algebraic, graphical and numerical. The system I use, which I have given the acronym TALC, is formulated on the basis of encouraging the development of higher level thinking about mathematics and follows these guidelines:

- Techniques (components)
- Applications (modelling structure)
- Life/career—linking what students have learnt to their engineering field or engineering work

- Creativity (something new, innovative or original)

I present an example of an assessment task that I have used with engineering students.

Engineering mathematics 1: Assignment 1 This assignment deals with linear transformations. Linear transformations are used in computer graphics and other areas. You will need to define terms used in your work. For example, if you find an example that uses a sparse matrix you would need to define what a sparse matrix is. You need to reference any material you have found on the Internet or in books—including definitions. There will be a question in the final examination that asks you to use a linear transformation. For this assignment, consider the unit square to be the square in the first quadrant with corners $(0, 0)$, $(1, 0)$, $(1, 1)$ and $(0, 1)$:

Question 1 (7 Marks)

(a) What is a linear transformation?

(b) Consider the matrix $R = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix}$ and the vector $\mathbf{v} = \begin{pmatrix} 1 \\ 2 \end{pmatrix}$. Choose different values of ϕ and demonstrate graphically what happens when you evaluate $R\mathbf{v}$.

(c) Consider the matrix $S = \begin{pmatrix} s & 0 \\ 0 & s \end{pmatrix}$.

(i) What effect does S have on the vector $\mathbf{v}$?

(ii) What effect does S have on a general vector $\begin{pmatrix} x \\ y \end{pmatrix}$.

(iii) What effect does S have on the unit square?

(d) Consider the matrix $T = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$.

(i) What effect does T have on the unit square?

(ii) Find the matrix transformation that will rotate the unit square around the y axis.

(iii) Find the matrix transformation that will reflect the unit square around the line $y = x$.

(iv) Find the matrix transformation that will reflect the unit square around the line $y = -x$.

Question 2 (8 Marks) Imagine you are tutor teaching how to rotate, translate and skew a unit square using matrix transformations to our class. In about four pages, design a handout to teach this topic to the class.

5 Conclusion—Working as an engineer

Engineering students are on a journey to a career, and mathematics is one of the essential pieces of equipment. As university teachers, we try to set them up for their futures but we do not always succeed. The study of mathematics has much to offer an engineer beyond a mere set of techniques, nonetheless, the use of mathematics within the job of engineer is not necessarily self-evident to an undergraduate student, and hence it is not easy for students to make a connection between what they are learning at university and what they will be doing after graduation. Our research shows that some of our students have recognised the importance of skills such as problem solving and logical thinking in their journey to becoming a professional, while for most we need to make a greater effort in clarifying the link between university subjects and the workplace.

Acknowledgements I extend warm thanks to all the students who took part in the study, as well as to all the other researchers involved.

References

[1] Graduate Careers Council of Australia. Website, 2007. http://www.gradlink.edu.au C514

[2] O. Bringslid, G. Rodriguez, and A. de la Villa. dMath: a European project for the restatement of mathematics teaching. *Eur. J. Eng. Ed.*, 32(1):9–20, 2007. C515

[3] A framework for qualifications of the European higher education area. Technical report, Ministry of Science, Technology and Innovation, Denmark, 2005. http://www.bologna-bergen2005.no/Docs/00-Main_doc/050218%_QF_EHEA.pdf C515

[4] H. Hult, M. Abrandt Dahlgren, L.O. Dahlgren, and H. Hård af Segerstad. Freshmen's and seniors' thoughts about education, professional identity and work. *Proc. Aust. Ass. Res. Ed.*, 2003. http://www.aare.edu.au/03pap/dah03725.pdf C515, C516

[5] P. Kent and R. Noss. Mathematics in the university education of engineers. Technical report, Ove Arup Foundation, London, 2003. http://www.ioe.ac.uk/rnoss/REMIT/Kent-Noss-report.pdf C515

[6] L. Kirkup, L.N. Wood, G. Mather, and P. Logan. Are you being serviced? Promoting quality service teaching. In *Uniserve Science*, pages 37–42, Sydney, 2003. C516

[7] I. Markes. A review of literature on employability skill needs in engineering. *Eur. J. Eng. Ed.*, 31:637–650, 2006. C515

[8] R. Martin, B. Maytham, J. Case, and D. Fraser. Engineering graduates' perceptions of how well they were prepared for work in industry. *Eur. J. Eng. Ed.*, 30:167–180, 2005. C515

[9] P. Petocz, A. Reid, L.N. Wood, G.H. Smith, G. Mather, A. Harding, J. Engelbrecht, K. Houston, J. Hillel, and G. Perrett. Undergraduate students' conceptions of mathematics: An international study. *Int. J. Sc. Math. Ed.*, 5:439–459, 2007. C517

[10] A. Reid, L. Wood, G. Smith, and P. Petocz. Intention, approach and outcome: university mathematics students' conceptions of learning mathematics. *Int. J. Sc. Math. Ed.*, 3:567–586, 2005. C514

[11] L. Wood and A. Reid. Conversations with graduates: reflections on learning mathematics. In *Proc. 3rd Int. Conf. Teaching of Mathematics at the Undergraduate Level*, Istanbul, Turkey, 2006. Turkish Mathematical Society. Issued on compact disc. C516

[12] L. Wood, G. Smith, G. Mather, A. Harding, J. Engelbrecht, K. Houston, G. Perrett, J. Hillel, P. Petocz, and A. Reid. Student conceptions—understanding performance. In *Proc. 3rd Int. Conf. Teaching of Mathematics at the Undergraduate Level*, Istanbul, Turkey, 2006. Turkish Mathematical Society. Issued on compact disc. C517

[13] L.N. Wood. *Research in mathematics education in Australasia 2000–2003*, chapter University mathematics teaching and learning. Flaxton: Post Pressed, 2004. Editors B. Perry, G. Anthony and C. Diezmann. C516

Author address

1. **Leigh N. Wood**, Macquarie University
   mailto:leigh.wood@mq.edu.au