Mathematics for Engineering Education: What Students Say

Mary Coupland
University of Technology, Sydney
<mary.coupland@uts.edu.au>

Anne Gardner
University of Technology, Sydney
<anne.gardner@uts.edu.au>

Georgina Carmody
University of Technology, Sydney
<georgina.carmody-2@uts.edu.au>

In the context of curriculum renewal, 111 engineering students were surveyed about their perceptions of the relevance of topics in their core mathematics and science subjects to their later engineering studies. The mathematics topics rated most highly were trigonometric functions and linear algebra. Differences by student major and by stage through the degree are described. The implications of low ratings and ways to address these are discussed.

This research was undertaken as part of a curriculum renewal project, funded as a Learning and Teaching Performance Fund initiative, in which academics from the Faculties of Science and of Engineering at the University of Technology, Sydney are collaborating to renew the mathematics and science curricula in the Engineering degree course. The curriculum renewal project aims to further enhance the relevance of mathematics and science to engineering students, so that students have the enabling mathematical and scientific knowledge and skills to engage confidently and effectively in their engineering studies and are prepared for life-long professional learning.

The project follows a design cycle of needs analysis, curriculum planning, design and development, implementation, and review and evaluation. This paper reports on part of the needs analysis, in particular the results of a survey of selected students in the degree.

Background

The place of mathematics and science in engineering education is currently under review. In Australia, the UK and the USA this is linked to a concern that at a time of high demand for engineering graduates there is a declining level of interest in choosing engineering courses, and a declining proportion of students studying mathematics and science to high levels in secondary schools (King, 2007). There is debate about the kind of mathematics needed by future engineers, with a shift towards the use of software packages and data handling "on the job" yet to be reflected in mathematics courses that remain based on algebra and calculus. On the other hand, algebra and calculus are used *within* engineering subjects, and a facility with mathematical notation and standard techniques is essential for following the development of the subject material in many engineering subjects. This raises the question of whether students are aware of the connections between the mathematics they study early in their degree and the later engineering subjects.

The literature review conducted for the project *Mathematics Education for 21st Century Engineering Students* (Henderson & Keen, 2008), reports on a range of subject designs and teaching methods that demonstrate adaptations to the needs of 21st Century engineering students. These include (1) using computer based methods such as web-based delivery, computer algebra systems and interactive software, (2) using flexible delivery, and support through tutoring and drop-in centres that are provided to address the issue of variability in students' mathematical preparation, (3) taking a multidisciplinary approach in various ways, such as team teaching of subjects designed by mathematicians and engineering academics working together, and (4) using problem based learning strategies. In recent years at the university where we work, all these strategies have been incorporated to some extent within our offerings of mathematics and science subjects within the engineering degree. As part of our curriculum renewal project, we needed to find out from stakeholders (including students and academic staff) the opinions about the success or otherwise of the teaching and learning in these subjects, especially in terms of revealing the connections between mathematics and later engineering subjects.

Survey of Students

Timing of the Survey

At UTS, all engineering students undertake two semesters of internship, working in their professional fields. These internships are scheduled for the first six months of the second and fourth years of the degree, as shown in Figure 1. All students study two mathematics subjects, usually taken as Core subjects in first year; and Physical Modelling, which is usually taken in first year, first semester as a Core subject.

TYPICAL PATTERN OF PROGRESS IN THE BE, DipEngPrac

YEAR 1		2		3		4		5	
SEMESTER 1	2	1	2	1	2	1	2	1	2
Core	Core	Internship 1	Core	Core	Core	Internship 2	Core	Core	Capstone Project
Core	Core		Field of Practice	Field of Practice	Field of Practice		Field of Practice	Field of Practice	Field of Practice
Field of Practice	Field of Practice		Field of Practice	Field of Practice	Field of Practice		Field of Practice	Elective	Elective
Field of Practice	Field of Practice		Field of Practice	Field of Practice	Field of Practice		Elective	Elective	Elective
	Engineering Practice Preview 1		Engineering Practice Review 1		Engineering Practice Preview 2		Engineering Practice Review 2		

Figure 1. Diagram showing the arrangement of subjects within the Engineering Degree.

It was decided to survey students in the subjects Engineering Practice Review 1 (EPR1) and Engineering Practice Review 2 (EPR2) in Spring semester 2007. These students had just completed either their first or second internship. It was felt that these students would have an opinion about the usefulness of their mathematics and science studies that would be shaped by their recent internship experience; and that those in EPR2 would also have completed more than half of their engineering subjects and have more to say about the way the mathematics and science subject supported their engineering subjects.

Design of the Survey

The survey was anonymous. Some biographical questions were asked, including the student's major. The body of the survey consisted of tables listing the content of core mathematics and science subjects, with columns to tick to indicate a response: either very relevant, somewhat relevant, or not relevant. The survey concluded with summary questions, asking for responses of "Agree", "Disagree" or "Neutral", to the statement:

> I found the current structure and order of topics within Mathematics, Statistics and Science subjects was satisfactory.

In addition, students were asked to rate in a similar way four statements about the connections between mathematics and science subjects and their later engineering subjects:

> I feel there is a clear connection between first year mathematics (statistics, physics, chemistry) and later engineering subjects.

Below these questions were the open-ended questions: "If you have ticked the 'disagree' column for any of these questions, please explain why" and "Any other comments?" with room to write responses.

Analysis and Results

We discuss some of the results and implications for the core first year mathematics subjects, Mathematical Modelling 1 (MM1) and Mathematical Modelling 2 (MM2). Each topic within the subjects was given a relevance rating by the students and the following scores were attached for the data analysis:

1. Not relevant;
2. Somewhat relevant;
3. Very relevant.

Average rating scores were used to get an overall idea of which topics seemed of higher relevance to the students. They were also used to gain insight into the difference of opinions between the students from different majors and stages through the degree. Tables 1 and 2 indicate the student ratings of topics in each of the core mathematics subjects. In each table, bold type indicates the topics with the three highest ratings, italics indicates the topics with the three lowest ratings. In Table 3 the average ratings are shown by the students' major, and in Table 4, by their stage in the course.

Table 1

Student Ratings of Topics in Mathematical Modelling 1

Topics in Mathematical Modelling 1	**Mean**	**N**
Introduction to physical and mathematical modelling	2.33	110
Functions, measurement, and interpreting physical results	2.37	110
Differentiability	2.30	110
Differential equations arising from physical problems	2.23	109
dy/dx = f(x)	2.25	109
dy/dx = k y	2.21	109
dy/dx = a y + c	2.21	109
Idea of solution by series	2.05	110
Growth and decay problems	2.01	109
Oscillatory motion including SHM, damping, forced oscillations, resonance	2.10	109
Trigonometric functions	2.38	110
Inverse functions and inverse trig functions	2.05	110
Complex numbers: polar, Cartesian, exponential form, DeMoivre's theorem	2.08	110
Integration from first principles (Riemann sums)	*1.93*	106
The logarithm function	2.22	109
Methods of integration: by substitution, by parts, by partial fractions	2.25	110
Using a table of integrals	2.11	109
Introduction to non-linear oscillations	*1.96*	111
Computer algebra system: *Mathematica*	*1.94*	111

Table 2

Student Ratings of Topics in Mathematical Modelling 2

Topics in Mathematical Modelling 2	**Mean**	**N**
Linear algebra:	2.32	81
solutions to sets of equations resulting from particular problems	2.35	108
the need to develop a variety of ways of solving sets of equations	2.36	107
matrices and determinants	2.14	108
eigenvectors and eigenvalues	1.94	108
Vectors: a standard treatment building on that given in Physical Modelling	2.22	108
Partial derivatives, waves and temperature distributions as illustrative examples	2.07	108
Using partial derivatives for rates of change	2.13	103
Optimisation (critical points and their nature for functions of two variables)	2.02	105
The method of least squares	1.85	105
Multiple Integrals: theory and practice	2.00	106
Multiple integrals: Applications	2.01	106
Computer Algebra System: *Mathematica*	1.88	107
Probability with a focus on the determination of the reliability of a system of components in various engineering contexts	1.96	104
Descriptive statistics – graphical	2.12	106
Variance, measures of location and measures of spread	2.08	104
Skewness and kurtosis	*1.80*	104
Probability distributions	2.02	106
Conditional probability and bi-variate probability	*1.85*	105
Inference of means and proportions in populations	1.88	104
Use of statistics software *Minitab*	*1.73*	108

Table 3

Averages of Student Ratings of Topics by Student Major

	Mathematical Modelling 1		**Mathematical Modelling 2**	
Engineering Majors	Mean	N	Mean	N
Civil	2.04	35	1.97	35
Mechanical	2.22	31	2.12	28
ICT & Electical	2.20	45	2.03	45
Total	2.15	111	2.03	108

Table 4

Averages of Student Ratings of Topics by Students' Stage in Degree

	Mathematical Modelling 1		**Mathematical Modelling 2**	
Stage in degree	Mean	N	Mean	N
EPR 1 (usually 4th semester)	2.05	62	1.89	60
EPR 2 (usually 8th semester)	2.28	49	2.22	48
Total	2.15	111	2.03	108

As seen in the above tables, there appears to be a slightly higher overall average rating for Mathematical Modelling 1 (MM1) topics compared with Mathematical Modelling 2 (MM2) topics. In both of these subjects, the Civil engineering majors tended to give the lowest ratings, and the Mechanical engineering majors tended to give the highest ratings. When comparing the EPR 1 group to the EPR 2 group, the EPR 2 group rated topics more highly for both of the Mathematics subjects than did the EPR 1 group.

Statistically Significant Results

The Civil engineering majors tended to rate mathematics topics lower on average than students in other majors. They rated significantly lower the topic of complex numbers, with average rating of 1.74 compared with 2.26 and 2.23 for the Mechanical engineering and ICT/Electrical engineering majors. The results are illustrated in Figure 2.

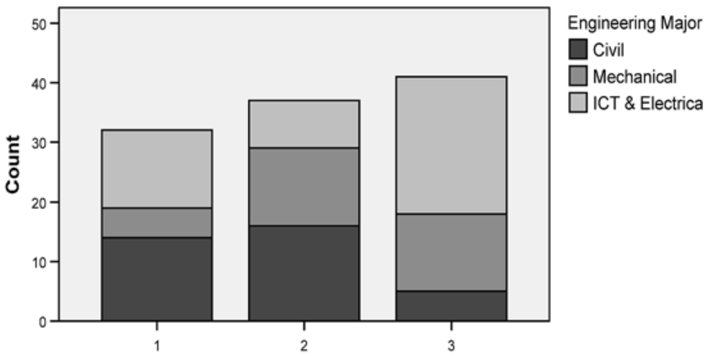

Figure 2. Chart showing different ratings of the topic Complex Numbers by students in different majors.

Similarly, the ICT & Electrical majors gave significantly higher ratings for solving certain types of differential equations with a mean of 2.38 compared to 2.13 and 2.06 for the Mechanical and Civil engineering majors. This is illustrated in Figure 3.

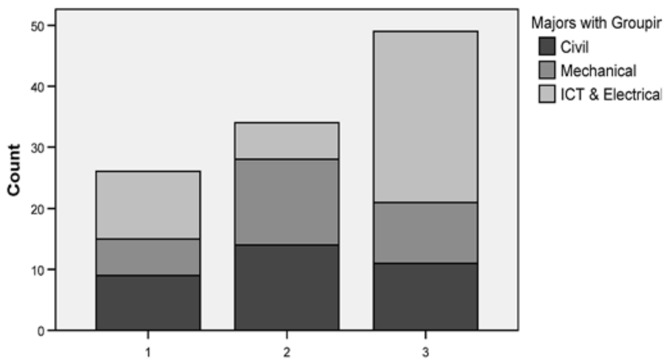

Figure 3. Chart showing different ratings of the topic "Solve dy/dx=ay+c" by students in different majors.

There was not much difference between EPR 1 and EPR 2 ratings of the MM1 topics, however there were significantly different ratings in many of the MM2 topics. The topic "solving sets of linear equations" was rated above average by the EPR 2 group, with a mean rating score of 2.54 compared to 2.20 by EPR 1 students; and the topic "eigenvalues and eigenvectors" was rated below average by the EPR 1 group at 1.78 compared to 2.15 by the EPR 2 group.

The most remarkable finding however, was in the statistics topics within MM2. The EPR 2 students rated every statistics related topic significantly more highly than did the EPR1 students. This is a clear indication that the students early in their degrees have not yet encountered the importance of the use of statistics in engineering.

Results for the Summary Questions and Student Comments

Table 5 shows the responses to the summary questions. It is clear that many students do not appreciate the connections between their experiences in mathematics subjects and in later engineering subjects.

Table 5

Responses to the Final Summary Questions about Mathematics Subjects.

Please rate the following	Agree	Neutral	Disagree
I found the current structure and order of topics within Mathematics, Statistics and Science subjects was satisfactory	62 *60.2%*	38 *36.9%*	3 *2.9%*
I feel there is a clear connection between first year mathematics and later engineering subjects	54 *52.4%*	40 *38.8%*	9 *8.7%*
I feel there is a clear connection between first year statistics and later engineering subjects	30 *29.1%*	51 *49.5%*	55 *21.4%*

To gain some idea of the reasons for these responses, it is useful to consider the range of students' comments. Starting with positive comments, we find:

> "These subjects give the student the analytical skills to tackle any job." ICT, EPR 1

It is clear that the students in different majors see different mathematical needs:

> "Because there is certain subject need math such as CA [Circuit Analysis] & other subject and it should be covered very well - exponential & Laplace & different way of differential equation." ITC, EPR 2

> "Math Mod 1 & Math Mod 2 doesn't seem at all relevant to later civil & enviro eng. Subjects. This also goes with physical modelling. You don't really need to know the stuff in math mod 1 & 2 or physical mod to do civil or enviro eng." Civil/Environmental, EPR 2

Many students were critical of the statistics they were required to study in MM2, however some came to appreciate applications of statistics in other areas:

> "While overwhelmed with stats in MM2, it has played little role after that aside from looking up graphs" Civil, EPR 2

> "I don't recall having really used statistics anywhere else throughout degree. I still think the knowledge of them is important." Mechanical, EPR 2

> "The concepts of MM1 & 2 should be swapped, as the advanced trig I found was not as useful as statistics…. I found that the statistics course has been very important in many of my subjects (both engineering & business (econometrics)). It would be useful to introduce this initially to first year students, as it would assist their later subjects with a greater understanding of it." ICT, EPR 2

For academics about to redesign subjects, these comments are extremely important:

> "I think the Physics and Math Mod 1 subjects could be taught in a more relevant way to engineering. Some of the content is very useful in later subjects however a clearer connection to later subjects should be shown in these early subjects." Civil, EPR 2

> "All Maths is done in first year, so by 4th year some concepts have been forgotten. Maths sometimes meaningless without engineering application." Mechanical, EPR 2

Discussion and Implications

What Does a Low Relevance Rating Mean? What Can be Done About it?

The content of the core mathematical subjects consists of standard topics for engineering degrees. When a topic is rated as "not relevant" by students one needs to ask whether (1) the topic has actually become outdated, (2) the relevance has not been made evident by the style of teaching and type of examples discussed, or (3) perhaps students have not experienced enough of their engineering subjects to see the relevance for themselves. Our approach is to gather more information from engineering academics to assist with answering this question, especially if we suspect the answer is likely to be (1). A topic may indeed be outdated in terms of expectations of pen and paper problem solving in cases where the standard in professional practice is to use a software package. This needs to be investigated topic by topic, as moving too quickly to software tools without understanding basic concepts brings its own dangers. Eric Love (1995) writes:

> Expert users are able to think of such aspects as 'tools' because they project their previous experiences of paper-and-pencil mathematics on to the situation in the computer software and use these tools as surrogates for their previous manual techniques. Learners, of course, do not have this previous experience and thus have the double handicap of knowing neither under what circumstances they might use the tool, nor how it works. (p. 114)

One does see a change towards valuing conceptual understanding over accurate by-hand calculations, however conceptual understanding may require a certain amount of by-hand calculation in its formation.

It is clear from the results presented in this paper that (3) is often a factor to be considered. In this survey, later stage students had experienced more uses for statistics than early stage students. The differences in ratings of some topics by students in different majors could also be considered here. This is where guest appearances by lecturers of later stage engineering subjects may help to motivate and interest students.

As far as (2) is concerned, we can already report on three changes that have interested the students in mathematics classes since this survey was conducted. First, we are trialling the relegation of routine exercises to be done on "hand-in" sheets, which are due at the *beginning* of tutorials. This makes time available in tutorials for discussion of practical engineering applications of the mathematics. Engineering academics are being invited to provide the practical engineering applications. Additional peer-supported study groups are available for students who need assistance with the basic routine exercises, and we also have a drop-in tutor system available through the Mathematics Study Centre. Second, where topics permit, engineering academics are making appearances in mathematics lectures to "team teach". For example, a very popular lecture involves a structural engineer talking about deflection in beams. At the vital point when integration is required to calculate the second moment of area for the cross section of a beam, the mathematics lecturer steps in to explain how the integral is initially set up as a Riemann sum. Third, the balance of topics between revision of high school material, and the first two semesters of university mathematics is being revisited. We hope this will allow more time for the second semester mathematics topics to include the development of engineering applications.

Conclusion

The student survey reported here is one of several methods of data collection to support curriculum change in our situation. The voices of students need to be heard, and their opinions need to be weighed along with those of other stakeholders. Interviews with engineering subject co-ordinators have provided more information, and the actual process of conducting those interviews has started a process of collaboration that we intend to continue. As noted by Broadbridge (2007, p. 18), "Students have a higher satisfaction rating where there is regular consultation between Maths and Engineering faculties on curriculum planning and where space and time are provided for drop-in assistance."

References

Broadbridge, P. (2007). *Mathematics education for 21st century engineering students: Scoping project for disciplines-based initiative.* Presentation to the Symposium *Mathematics for 21st Century Engineering Students*. Australian Mathematical Sciences Institute, December 2007. Accessed April 2008 at http://www.amsi.org.au/carrick_seminar_program.php

Henderson, S. & Keen, G. (2008). *Mathematics education for 21st century engineering students: Literature review*. Australian Mathematical Sciences Institute. Accessed April 2008 at http://www.amsi.org.au/

King, R. (2007). *Mathematics for engineers: Observations from the review of engineering education.* Paper presented at the Symposium Mathematics for 21st Century Engineering Students. Australian Mathematical Sciences Institute, December 2007. Accessed April 2008 at http://www.amsi.org.au/carrick_seminar_program.php

Love, E. (1995). Software for mathematics education. In L. Burton & B. Jaworski (Eds.), *Technology in mathematics teaching - A bridge between teaching and learning* (pp. 109-118). Bromley, U.K: Chartwell-Bratt.