Mathematics in Engineering Education: Meeting the Challenge of Cultural Change

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1 Introduction

A Report on a major review of engineering education was published in 1996 [1]. In the Foreword to the Report, the Chair of the Review Committee, Peter Johnson, stated that the Review recommends *"no less than a culture change in engineering education which must be more outward looking with the capability to produce graduates to lead the engineering profession in its involvement with the great social, economic, environmental and cultural challenges of our time"* (p.6).

In the 8 years since the release of the Report, there does appear to be change taking place in the undergraduate programs offered by many engineering schools. However (from informal discussions) it is apparent that many mathematics staff engaged in providing service mathematics for engineering students are not familiar with the culture change expressed in the Review (see p.7). *"Courses should promote environmental, economic and global awareness, problem solving ability, engagement with information technology, self learning and lifelong learning, communication, management and teamwork skills, but on a sound base of mathematics and engineering science."*

John Webster, in an overview of the Review [2] included the following reasons for it.

- The emergence of new engineering disciplines and new technologies.
- Significant changes in the capacities of tertiary students at the point of entry.

He also insisted that there should be emphasis in undergraduate programs to move away from the present focus on examinations, in one form or another. Undergraduate courses should cover problem definition and problem solving, model building and simulation.

In a paper delivered at the third Mathematical Education of Engineers conference, UK [3] the author discussed the question: Is there a gap between the changing needs of engineering education and the current service offered by mathematics departments? The paper also called for more dialogue between mathematicians and engineers by forums and special interest networks. The aim being, with joint effort, to co-operatively generate an appropriate mathematically sound but relevant and technology enhanced mathematics education for the engineer of the future.

So what does the service mathematics community need to do to address the changing culture in engineering education? This paper outlines some of the key areas in mathematics for engineering undergraduate programs which are crucial in any effort to make a positive contribution to the cultural change in engineering education. The reasons for including these key areas are based on a current project and comments by a range of researchers in recently published reports.

2 The Challenge for Mathematics Departments

Of course there are mathematics departments which are, in various forms, making efforts to address the real needs of engineering students. In addition to the Australian Review of Engineering Education, some statements drawn from the UK Report, Engineering Mathematics Matters [4] are particularly relevant.

- *Core subjects should be integrated with laboratory experiments and simulation to include mathematical modelling representing real engineering problems....essential core subjects of mathematics, statistics and computing to provide a secure base for future self learning.* (Report of UK Institutions of Mechanical Engineers, The Foundation of Engineers 1998).
- *Courses must provide a core of underpinning science and mathematics appropriate to the discipline, with graduates having an understanding of the mathematical basis of the discipline for analysis and communication.* (Report of UK Institution of Electrical Engineers, 1998).

Although the Engineering Mathematics Report refers to the European scene these statements are also deemed to be pertinent to the education of the Australian engineer.

During 2002 the author has been involved in a project to review the mathematics component of the engineering undergraduate programs offered by the Faculty of Engineering and Physical Systems, Central Queensland University. Rather than report on the actual content of the mathematics courses this paper concentrates on the challenges presented by mathematical modelling, assessment, and the increasing move to Problem Based Learning (PBL) in engineering education. It is acknowledged that the importance of each of these three topics could warrant a separate paper as follow up reports.

3 Mathematical Modelling in a Change of Engineering Culture

Whether mathematical modelling, as a skill involving problem identification and the process of listing assumptions, defining variables and setting up mathematical relationships, should be included in the engineering mathematics curriculum for undergraduates continues to be a topic of debate. As well there are times when the use of existing mathematical models and the process of setting up a model has been confusing for the student.

Mathematical modelling in high school mathematics is currently receiving a lot of positive attention. The mathematics syllabuses in high schools in several Australian States now include mathematical modelling as an essential component. The Objectives of the Queensland Senior Mathematics B Syllabus [5] (the normal mathematics prerequisite for engineering undergraduate programs) include the heading, Modelling and problem solving. Under this heading, the Syllabus states (see p.5):. *"By conclusion of the course students should be able to demonstrate the category of modelling and problem solving through*

- *understanding that a mathematical model is a mathematical representation of a situation*
- *identifying the assumptions and variables of a simple mathematical model of a situation*
- *forming a mathematical model of a life-related situation*
- *deriving results from consideration of the mathematical model chosen for a particular situation*
- *interpreting results from the mathematical model in terms of the given situation*
- *exploring the strengths and limitations of a mathematical model".*

The process of modelling can be enhanced by the use of technology, in particular, graphics calculators. The Syllabus contains a specific statement on technology: *"Graphing calculators, for example, let students explore and investigate: they assist students with the understanding of concepts, and they complement traditional approaches to teaching".* (p.10)

However skills audits of the new intake of students into engineering programs at CQU reveal little understanding of this definition of mathematical modelling. If is suggested that the process of mathematical modelling (as defined in the Queensland Syllabus) can be developed in first and second year engineering mathematics. Joint teaching with engineering staff in third and fourth year could then see the process strengthened as students encounter mathematical modelling within the context of engineering problems.

As far back as 1984, there was a strong move in the UK to have mathematical modelling included in the curriculum for engineering students. Glyn James, of Coventry University, one of the champions of the push for mathematical modelling in undergraduate curricula, ran a series of workshops for mathematics staff some years ago. On modelling in engineering programs James stressed that it is essential that engineering staff become aware of the importance of mathematical competence and the growing need for modelling skills in their graduates. They themselves should also highlight these modelling skills in the teaching of their own disciplines and not be satisfied with using passive models [6]. At the time he was aware that many engineering staff were developing modelling skills in their students but there was clearly a need for retraining in this direction for both engineering and mathematics staff. Many mathematics staff prefer the use of passive models, these being less demanding on their time and, less frightening than the modelling approach. Nineteen years later, in some institutions, has anything changed?

Johnny Ottesen is a staff member at Roskilde University, Denmark, where a problem based/modelling approach to teaching mathematics has been developed over the past 25 years. Ottesen [7] asks the question, "What can modelling do for mathematics and its teaching and learning?" He stresses the difference between mathematical models and mathematical modelling. After presenting a first year course on basic analysis, modelling and simulation he found that when some students realise that when they are experiencing difficulties in modelling, they become able to work on reducing these difficulties in a conscious way, and from here a deeper understanding is often gained. Students may be able to overcome some of these difficulties through modelling, not only because they are motivated but also because they experience different points of view.

Melvin Nyman and John Berry [8] argue that the inclusion of mathematical modelling in the curriculum empowers students to develop the oft-quoted generic skills of problem solving and team working communication. They state that a mathematics program of study needs to retain the development of mathematical skills. The ability to solve real problems using mathematical models does depend on the ability to apply mathematical algorithms and rules. The modes of thinking that recognise mathematics are often a more useful attribute than knowledge of any mathematical fact, algorithm or rule. A graduate who is able to recognise patterns, generalise, improve and extend models has the skills to work at a system level in business and industry.

Mathematical modelling at all levels of mathematics education has been the theme for the international conferences on the Teaching of Mathematics and Applications (ITCMA). At ICTMA9 the author [9] summarized the benefits to learning provided by the inclusion of mathematical modelling in the curriculum, especially for engineering students. *"If interest and motivation are developed through relevance, and students have the resources to experiment, explore and investigate the analytic, graphical and numerical aspects of a problem, content will be consolidated and new learning can take place through modelling activities"* (p.146).

Richard West describes mathematical modelling as a strengthening thread in mathematics courses at the United States Military Academy, West Point [10]. He stresses that curriculum reform in mathematics should have a primary focus of empowering students and that mathematical modelling can play a vital role in contributing to a cultural change in mathematics education. West lists interdisciplinary projects, which can support this cultural change; the Interdisciplinary Lively Applications Projects (ILAP's) (Available on the COMAP website http://www.projectintermath.org/products/listing/. The importance of mathematical modelling is also illustrated by the current call for contributors to an International Committee for Mathematics Instruction (ICMI) study in Applications and Modelling in Mathematics:
www.mathunion.org/ICMI/ICMIstudies_coming.html

There is little doubt in the minds of many engineering educators that there is a definite role for mathematical modelling and it should be integrated into the curriculum. An additional argument for modelling is that it presents a marvellous opportunity to create an environment for learning to be embedded in reality.

4 Problem Based Learning (PBL) in Engineering Education.

As the Institute of Engineers, Australia, promotes the implementation of PBL in engineering education, mathematics departments which provide service for engineering faculties will need to work closely with engineers, physicists and other discipline experts to ensure that they will make a positive contribution to PBL in engineering education. In the Preface to his book on Industrial Mathematics Charles MacCluer [11] urges the Instructor to ensure that students obtain experience in group project development and that, each student must do simulation and numerical experimentation individually. He states that insisting on *"elegant analytic solutions is not cost effective and is not in the spirit of the course (or of industry)"*.

At a Forum on Mathematics in PBL in Engineering Education at the 13th Australasian Association for Engineering education, (A^2E^2) [12] the provision of mathematics services for PBL was seen as a challenge for mathematicians and engineers. In particular the Forum agreed that:

- Students would need to thoroughly understand the content and processes of first year engineering mathematics with less time devoted to tedious manipulation and more on developing understanding with emphasis on conceptualisation.
- There would need to be very close liaison between engineering staff involved with PBL and the mathematics staff providing the service.
- Mathematical modelling would play a vital role in developing comprehensive understanding and the connection between mathematics and physical reality.
- Students would benefit if engineering staff and mathematicians were to present joint tutorials and other group learning sessions to develop mathematics for PBL.
- Technology would also continue to play a vital role in student learning outcomes.
- Assessment of mathematics in PBL would acquire a joint effort and critical review of the current assessment instruments.

To enable a continuation of this important dialogue it was proposed to establish a Mathematics in PBL Engineering Education Working Group. However Networks already exist on the AAEE website. The PBL Network can be assessed at www.aaee.com.au/networks/pbl.htm and the Engineering Mathematics Educators Network can be accessed at www.aaee.com.au/networks/engmath.htm

5 Assessment in Engineering Mathematics

At the 2002 A^2E^2 Conference, Jackie Walkington and David Dowling presented for discussion, the paradox of best practice in assessment and the constraints of implementation [13]. They list the important principles that underpin assessment in undergraduate programs. In particular, assessment should:

- Measure student learning (and student learning is continuous).
- Be aligned with course objectives.
- Recognise student diversity.
- Encourage student learning.
- Have standards which are transparent to the students.

Whilst academic staff may well be aware of these features of sound assessment, Walkington and Dowling outline some of the barriers to implementation of these features. The student body is no longer homogeneous. There is a diversity of learning styles, backgrounds and attitudes. Their message was that catering for this diversity requires change not only at the classroom level but at all levels within the engineering education framework. The barrier to effective assessment is the difficulty/inability to truly get to know about the diversity of the student's backgrounds. They also discuss the lack of resources and the attitude of some staff to the acceptance of changing assessment practices. In addressing the problem they argue that; (i) assessment needs to be part of the initial design of a course, both formative and summative assessment is required, and, (ii) a holistic approach is required if an understanding that effective change seeking long-term improvement to teaching/learning within a faculty is to be achieved.

As teaching and learning strategies in engineering are influenced by PBL there is a need to complement the team approach to problem solving by including more of this activity in the mathematics component of undergraduate programs. Joshua Harrison of the Department of Mechanical Engineering at the University of Queensland, writing on assessment in modern engineering [14], warns that as engineering embraces new technologies and advances in the skills required by the modern engineer make demands on the curriculum, only two options are available, either exclude important subject matter from the curriculum or make an attempt to cover all important subject areas, dedicating less time to each specific area than was previously given.

Harrison believes that the choice of scope in engineering undergraduate education can effect, and be effected by, the methods used to assess student performance. He believes this is true because problem solving is central to engineering assessment, and problem-solving ability is related to the depth of learning in the topics covered. The answer appears to be assessment methods, which incorporate a balance of criterion-based assessment to ensure a minimum standard and norm-based assessment to counteract yearly variations in teaching styles and textbooks.

Otto Rompelman [15] of Delft University argues that the rapid changes taking place in the objectives of engineering education demands that assessment methods reflect this change of culture. He gives examples of what is defined as the *testing* culture and the *assessment* culture (due to McDowell in 1999). In the testing culture the emphasis is on ranking the student whereas the emphasis in the assessment culture is on describing the overall performance of the student. He refers to research which illustrated that even if students pass traditional examinations they lacked understanding of the fundamental concepts of the subject...the difficulties he listed as:

"Lack of integration between computational skills and theoretical knowledge.

Missing or inconsistent intuitive anchoring of conceptions, models, principles, etc.

Insufficient ability to assess assumptions and/or conditions for models, their level of idealization and what information is required in order to solve a problem" (p.347).

Inspection of a selection of assessment instruments in engineering mathematics indicate that this is an area which is overdue for a critical review. The learning outcomes must be clearly defined and the assessment must reflect the learning outcomes and include group projects, individual projects and a variety of instruments rather than a final examination and written assignments. In the new culture of engineering education, problem based learning is gaining momentum. Assessment in engineering courses is beginning to reflect the learning outcomes of PBL, and so assessment in engineering mathematics must also be rigorously reviewed in partnership with the assessment in engineering education.

Conclusion

Last year (2002) the Mathematics Working Group (MWG) of the European Society for Engineering Education (SEFI) presented a core mathematics curriculum for the European engineer [16] Apart from listing detailed content of topics in mathematics, the curriculum also draws attention to the on-going challenges presented by

- The diversity of mathematical ability of entrants to engineering programs.
- The need for those teaching mathematics to be aware of applications of mathematics in engineering and changes taking place in mathematics education in high schools.
- The early introduction of mathematical modelling into the education of engineers.
- "Traditional" methods of assessment – do they really meet the objectives of learning outcomes?
- The role of technology in mathematics for engineers the concern of the "black box approach" favoured by some engineers.

These challenges are particularly relevant to the challenge of addressing the cultural change in engineering education in Australia.

The references in this paper do indicate that there are educators who are making a positive contribution to the cultural change taking place in engineering education. However there is a vital need for the mathematics community to establish formal collaborative dialogue with the engineering fraternity. One way of establishing this dialogue is to set up joint working groups involving mathematicians, engineers and physicists. The working groups should meet on a very regular basis and be the venue for ensuring the needs of the engineering students, within the resources of the providers, are met. This cooperative effort is too important to be left to ad hoc and individual communication. Unless there is joint effort it may well be that the cultural change in engineering will progress and the contribution from mathematics will decline.

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