Mathematics in PBL Engineering Undergraduate Education: Challenges and Vision for the Future

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Abstract: *A recent CQUniversity funded project entitled "Mathematics in engineering programs: enhancing student learning using PBL methods", generated by the authors, attempted to determine the extent to which project based learning methods are employed to deliver mathematics content in engineering programs. The project also conducted in-depth interviews with three representatives from higher education, professional and research organizations, to gauge the degree to which project based learning methods might enhance learning outcomes in engineering mathematics*

"Engineering students are application-oriented and so would benefit by having mathematics presented in context". This statement was made by a leading engineering educator in discussions during this project.

This paper will outline the results of a survey of 35 universities in Australia and New Zealand as part of the project, as well as an outline of some of the progress already made. Questions posed to the three representatives included: Will PBL mathematics contribute to a better mathematically educated engineer who will be more competent in the process of mathematical modelling? Is this a realistic vision for the engineer of the future?

Setting the Scene

Problem or Project Based Learning (PBL) is gaining momentum in undergraduate education in a range of discipline areas. Discussion on the future of mathematics in PBL in undergraduate engineering education has taken place over some years as engineering schools moved to PBL. One such discussion took place at the 1998 AAEE Conference held at the Gladstone campus of CQUniversity. A Forum Discussion paper (Fuller 1998) debated the questions:

- How can mathematics contribute to PBL in engineering programs?
- Is there a need for a major review of the way in which mathematics is presented in engineering programs?
- Is there a need to critically examine the mathematics content of PBL programs in engineering?

A major Carrick, (now the Australian Learning & Teaching Council) funded project, lead by Phillip Broadbridge, then Director of the Australian Mathematical Sciences Institute, resulted in a comprehensive Report: Mathematics Education for 21st Century Engineering Students (Broadbridge & Henderson, 2008) on the outcomes of that project. Included in the summary of that Report is the statement,

> *"With goodwill between the disciplines and some co-ordinated developments, we believe that engineering mathematics can be made more appealing. This could include more reference to engineering contexts in mathematics lectures".*

Recommendations arising from the project include reference to joint mathematics curriculum committees, collaborative teaching and mathematics staff teaching engineering mathematics within engineering contexts.

Engineers Australia, teamed up with the Australian Technology Network of universities 'to work on curriculum reform' in engineering programs. The Executive Summary to the recent Carrick Institute Report, Mathematics for 21st Century Engineering Students, included the statement 'Mathematics educators have been trialling and adopting a variety of strategies to engage the students and help them succeed. However the adaptations have been made at the local level with little oversight and coordination at the national level'. Recommendations from the Report include

- addressing the widening diversity of incoming students,
- establishment of joint mathematics curriculum committees
- collaborative teaching
- more application of mathematics to engineering contexts.

Another project, undertaken by the Australian Council of Engineering Deans, resulted in the Report, Engineers for the Future (King, 2008)]. One key and emerging theme for engineering education stressed in this Report is the consolidation of mathematical modelling and using such models in engineering tools and the need to "develop engineering students' mathematical ability in the context of engineering examples". We do believe that these two major projects provide modern groundwork for future positive outcomes in the mathematical education of engineers.

Engineering undergraduate programs at CQU do embrace PBL methods. However, as mathematics is a critical component of engineering degree programs, the following questions arise:

- To what extent is the mathematics component of engineering programs in Australasia embracing the concepts of project based learning methods?
- Which project based learning methods might enhance learning outcomes?

A CQU funded project, "Mathematics in engineering programs: Enhancing student learning using PBL methods" attempted to answer these questions.

Development of the CQU Project

Some of the work listed in the previous section has been receiving attention at CQU over recent years. These include:

- the establishment of the Mathematics Learning Centre and its long term support of engineering students,
- the establishment of the Engineering Mathematics Working Group , as a collaborative effort to improve learning and motivation in engineering mathematics at CQU, and
- research carried out leading to an internal report indicating that
    - engineering staff should play a greater role in the mathematics education of engineers to assist in setting engineering mathematics within an engineering context,
    - greater emphasis on mathematical modelling in engineering mathematics and
    - establishing links with other universities and other professional groups such as the Mathematics Working Group of the European Society for Engineering Education SEFI, (Milton Fuller is a member of the Mathematics Working Group), the MathsTEAM project and Helping Engineers Learn Mathematics (HELM) project in the UK.

Workshops and Forums on Mathematics in PBL Engineering Education have been presented at two AAEE conferences (the last in 2004). The Engineering Mathematics Educators Group was also established on the website of the Australasian Association for Engineering Education

www.aaee.com.au in an effort to generate dialogue. An international Network was established in conjunction with engineering mathematics colleagues in the UK, the objectives of which relate to the improvement of mathematics education of engineering students http://mec.lboro.ac.uk/international_network/index.html .

Further motivation for the work is provided by a special issue of the International Journal of Engineering Education (Volume 19, No 15, 2003) where Fuller and Jorgensen (2004) noted that 'no paper addresses the challenge of integrating mathematics into PBL in engineering education'.

There appeared to be a definite need for follow up action to build on the work which has already been carried out at CQU. A university learning and teaching grant was received to do this in 2009 and the project was entitled "Mathematics in engineering programs: enhancing student learning using PBL methods". The project strategy was to employ a qualitative investigation of the Australasian Engineering Education sector. This was to be achieved in a two part process of survey and follow up interviews.

The methodology chosen was:

- investigate the higher education sector to determine the extent to which project based learning methods are employed to deliver mathematics content in engineering programs. This was to be achieved by a survey of Engineering Schools in Australasia.
- conduct in-depth interviews with three representatives from higher education, professional and research organizations, to gauge the degree to which project based learning methods might enhance learning outcomes. The interviews were to explore issues and responses that arose from the survey.

The Survey

A comprehensive survey (approved by the CQUniversity Ethics Committee) was conducted. The invitation to participate was sent to Associate Deans Learning &Teaching (of Engineering schools), or their equivalent, at 32 universities. The main emphasis of the survey was to determine the extent to which PBL methods were being utilised in the delivery of engineering mathematics.

An abbreviated version of the survey questions is:

1. How long has your School/Faculty been using PBL methods in engineering education for its undergraduate program?
2. How many stand-alone compulsory mathematics courses are in the B.E. program
3. Is the mathematics component of the engineering programs taught by the staff of the mathematics department?
4. Do the mathematics courses in engineering programs involve PBL?
5. The best description of the mathematics courses in the engineering programs is that they involve ……
6. The mathematics courses in the engineering program use ….
7. What assessment methods are employed in mathematics courses in engineering programs?
8. What proportion of the total assessment for a course is team based?
9. Which areas best describe the compulsory mathematics courses in the BE program?
10. What mathematical software is used to support the courses?
11. Consultation regarding the mathematical content of engineering courses takes place mainly in …..
12. Any specific comments you would like to make regarding the design and delivery of mathematics content in engineering programs for you institution

Eleven responses were received, a response rate of 34%. At this stage no attempt has been made for a statistical analysis of the responses. The survey was to develop a general picture of the current state, and help develop the interview questions.

Summary of Survey Responses

Some responses of note included:

- 8 of the 11 responses indicated that their Engineering School had moved to PBL in engineering education.
- 8 of the responses indicated that in the main, engineering mathematics courses are taught by the mathematics department.
- The best description of the engineering mathematics courses is that the majority are traditional courses with some emphasis on problem-solving and engineering applications.
- Mathematical modelling and simulation was listed in 4responses.
- Only one stated that joint teaching teams of mathematicians and engineers are utilised.
- The most popular mathematical software in use is Matlab with 9 Schools using this aid to learning

The survey tends to indicate that PBL is starting to be considered in some Engineering Mathematics courses in Australasia, however the implementation does not appear to be fully consistent with the philosophy of PBL. For example, the assessment is still very traditional and the delivery still appears to be mainly lecture/tutorial as opposed to workshop/project based. The implementation appears to be more an attempt at introducing real problems, with lectures to deliver content rather than learning through the problem/project.

The Interviews

Three individual experts were identified as representing the major stakeholder groups. They are:

- Professor Philip Broadbridge – Director of the Mathematical Sciences Institute at the time of starting the project, and currently Head School of Engineering and Mathematical Sciences, LaTrobe University
- Associate Professor Roger Hadgraft – President of the Australasian Association for Engineering Education at the time the project began, currently Director, Engineering Learning Unit, University of Melbourne, and now also an ALTC Discipline Scholar
- Emeritus Professor Robin King – Executive Officer – Australian Council of Engineering Deans

Face to face interviews were conducted with the representative members. They were each given a copy of the survey document and summary, and this information was used as the basis for the interviews. The informally structured interviews asked the representatives to consider the outcomes of the survey and comment on trends, advantages and disadvantages of PBL in engineering mathematics. Transcripts of the interviews were created. A summary of the outcomes and possible future directions for PBL methods in engineering mathematics has been developed from the transcripts of the interviews.

Summary of Interviews

The interviews resulted in the following points as a summary.

- PBL in engineering programs does have a future in terms of improving integrated learning leading to positive outcomes. However there is a danger of falling back to the "old ways of teaching" unless there is an improvement in resources and there is a constant catalyst for making change.
- The main barriers for implementing engineering mathematics into PBL methods include limited resources, the drive for mathematics staff to be more productive in research leaving little time for innovative approaches to teaching and the poor mathematical ability of many students entering engineering degree programs.
- There is also difficulty in measuring the success of the change to PBL.
- There is a real need for improved dialogue between engineering and mathematics staff with emphasis on setting up PBL in the 3rd and 4th year of the programs. By this time the students should have a much improved competence in the process of mathematical modelling.

The perceived disadvantages of PBL in engineering mathematics are that:

- there will be less control over what students learn
- possibly fewer topics will be taught

- students may not gain a deep understanding of the key concepts of mathematics because of the emphasis on applications to engineering problems.
- there is also a risk that the mathematics may be perceived only as a tool in engineering education resulting in no real understanding which is necessary if the mathematics is to be applied to other real life problems and situations.
- again there is the resource implication as students will require a lot of guidance and support in coping with PBL methods.
- tutors will require a different set of skills to successfully support PBL mathematics students.

The perceived benefits are:

- that by bringing theory and application together a deeper appreciation for mathematics will result. students will be exposed to a wider range of staff which will benefit outcomes in terms of team work and group learning.
- having mathematics taught in context could improve the image of the discipline but how mathematics is set into the PBL methods will require a lot of time and effort on the part of both mathematics staff and engineers
- there would need to be a strictly controlled approach.
- once implemented mathematics in PBL could assist in students perceiving mathematics as an integrated component of the engineering program but engineering staff would need to be formally advised that the PBL projects have a mathematics requirement.
- mathematics staff would need to be aware that engineers do utilise a range of software packages to solve mathematically based problems.

Additionally the interviews indicated that engineering students should gain many skills from their mathematics education. The main skills being the ability to understand and use the process of mathematical modelling, especially in modelling real data. Skills in mathematical modelling does allow the use of a developed model to be used in other situations and also generates incentive to learn other topics in mathematics. Modelling must be the under pinning foundation for engineering mathematics. Students need to understand the mathematics used in computer packages and to be aware of the limitations of the packages. The whole purpose of the inclusion of mathematics in the engineering programs needs to be understood by the student.

The implementation of PBL into engineering mathematics will require a tremendous effort by all concerned including solving problems in timetabling staff to joint projects where irregular commitment is required. The consensus is that engineering mathematics using PBL methods would result in a better mathematically educated engineer.

Challenges for Future Development

Basic to the challenges and vision outlined is the real need for the students to become competent in the fundamental concepts of mathematics during the first year and part of the second year of the engineering undergraduate program. Mathematics staff have the responsibility, and rightly so, of ensuring that this competence is achieved by those who proceed. The challenges include the fact that to be successful the integration of mathematics into PBL engineering (and other disciplines) will require

- A joint venture between mathematicians and engineers in terms of designing engineering projects to develop mathematical modelling in the curriculum.
- A clear and well defined process for assessing joint projects
- Allocation of time, resources and funding for developing appropriate and timely projects.

However we believe that the vital step in addressing the challenges is to actually get things to happen. Hadgraft (2007) has outlined a conceptual model of curriculum design for a new engineering education. The stages of that model are to : Identify professional needs, create learning outcomes, assess and evaluate the learning outcomes and learning process. Also, importantly there is the urgent need to identify available learning resources. He also warns ,

> *"We now have 20 years experience in project-based learning and computer-assisted learning. However we have made little progress in properly integrating these two strategies. Nor have we made little progress in pooling our resources"*

There have been many debates and discussions on the mathematical education of engineers over the last 3 decades. In 2004 Fuller (2004) listed at an international meeting, several main challenges facing mathematics in engineering education in Australia. These challenges include:

- Generating closer and continuing liaison between engineering staff and mathematics staff who deliver the engineering mathematics courses.
- Developing the process of mathematical modelling as a principal learning outcome so that the mathematics of the program is perceived by the student to be an integral component of the engineering program.
- Constantly reviewing the assessment processes.
- Setting the scene for mathematics to make a positive contribution to PBL engineering education

These challenges are not new. Many dedicated educators, including those listed in this paper, are aware of the need to address the many challenges to achieve the vision of an overall improvement in the mathematical education of engineers, and of those students in other disciplines.

Conclusion

The project just completed has not only given us the opportunity to have an indication of current activities in engineering mathematics in some universities in Australia and New Zealand but also the need to re-visit some of the important projects which have occurred previously and deserve to be reviewed. What we need now if mathematics is to play a role in the transition of engineering education to PBL is action to locate, and make available to the mathematical community:

- More information on progress already being made in engineering mathematics in some institutions.
- Details of useful learning resources which already exist.
- Input from the mathematics community on this topic into the AAEE

We do believe that the future of engineering mathematics is in the hands of a community of professional educators who can move forward to ensure that engineering students of the 21st century will reap the benefits.

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