Student Engagement in Project-Based Courses in First Year Chemical Engineering at RMIT University

Margaret Jollands, Roger G. Hadgraft, Liam Ward, Ian Grundy

RMIT University, Melbourne, Australia

Abstract: In late 2001, RMIT Engineering embarked on a project to renew all undergraduate programs as capability driven curricula. The Bachelor of Chemical Engineering was renewed in 2004 and a new first year introduced in 2005. New project-based learning courses have been introduced, one per semester, to develop the capabilities in engineering design, teamwork, report writing, presentation, etc. The current research examines student engagement in the first of these courses, Sustainable Engineering, and compares this with a similar course in civil engineering, a traditional course in chemical engineering and first year mathematics.

Introduction

At RMIT the chemical and civil engineering programs have been "renewed" after being taught for 30 years in a more traditional style (teacher-centred)[1]. The accrediting bodies, Engineers Australia and the IChemE, have changed the way they accredit degree programs, placing emphasis on graduate outcomes (capabilities) rather than program inputs (course content)[2].

Stakeholders were consulted in the renewal process and the key outcome was that program renewal should focus on courses that would better develop the full range of graduate capabilities. Project-based learning was identified as the most appropriate teaching paradigm to develop a capability set made up of personal and professional development, sustainability, problem solving and decision-making, technical competence (engineering analysis), teamwork & leadership and communication.

This project-based learning was introduced through a stream of Engineering Practice courses, one per semester. In these courses, students develop their graduate capabilities through successively more complex projects across the breadth of industry sectors within chemical engineering. These projects include all aspects of project design, i.e. the technical, environmental, social and sustainability aspects. Hence, the technical content from other courses are integrated with realistic engineering problems. Sustainability concepts would provide an essential aspect of the framework for decision making in these new courses. Engineers in the 21st century must be capable of integrating the social, environmental and economic demands with the technical possibilities in their workplaces.

This paper explores how students have engaged in these new project-based courses, comparing them to more traditional courses in mathematics and biochemical and materials engineering.

Program renewal

RMIT University has identified as a key priority the transformation of all degree programs from a traditional content based curriculum to one based on the development of graduate ca-

Copyright © 2005, Australasian Association for Engineering Education

pability outcomes[3]. Drawing on capability theory[4], the initiative has brought with it a significant shift in many of the principles that have traditionally guided the design and delivery of undergraduate programs at RMIT.

In late 2001, the Faculty of Engineering (FoE) identified the renewal of all Bachelor of Engineering (BEng) programs as the leading edge of the program renewal implementation strategy[5]. In the first stage of that process, Chemical Engineering stakeholders, including staff, employers, graduates and students participated in the identification of graduate capabilities[1].

Several industry forums were organised for mid to late 2002 to further develop these capabilities. RMIT has a long tradition of Program Advisory Committees (PAC), which guide the university's programs. These forums used members of existing PACs, adding other senior industry figures and several recent graduates. At each meeting, one of the authors facilitated the group discussions.

From these meetings, the capacity to meet the following demands was seen as important:
- Cost management
- IT/IS and intellectual property
- Sustainable Development,
- Outsourcing/casualisation
- Teams and alliances
- Making quality and customer focus "real" (at the moment quality is not seen as proactive. It is compliance driven not strategic, not justified on the basis of adding value, and QA does not necessarily produce customer focus)
- The difficulty of achieving distinctive competence in such a dynamic, environment
- Generic capabilities becoming more important than specialist as an expression of what it means to practice. (an engineer, before a chemical engineer)

Some key improvements suggested for existing programs were:
- Focus on what's important – Be able to ask the right questions and think conceptually
- Use "real life" problems that require students to work with others from diverse backgrounds
- Develop field knowledge – pieces of equipment, industries, contracts
- Learn to work effectively in groups – requiring communication skills and the skill to manage relationships and conflict

The development of these broad skills requires an integrative approach to the curriculum. This has been implemented as an Engineering Practice course (subject) in each semester. These courses are usually design based. They are based around real problems that are designed to provide the sort of real world complexity listed above.

The eight Engineering Practice courses are:
- Sustainable Engineering
- Chemical Engineering Design
- Process Principles
- Data Collection and Analysis
- Experimental Investigations
- Process Systems Design
- Process Systems Integration
- Design Project

Copyright © 2005, Australasian Association for Engineering Education

Research Project is a ninth course that fulfils many of the same needs for solving complex problems.

The teaching methodology in these courses borrows from the problem-based learning tradition (eg [6]). Strictly speaking, it is more project-based than problem-based, particularly in the early years of the program where students receive a fair amount of scaffolding[7].

What is PBL?

Problem based learning (PBL) focuses on student-centred learning compared to a traditional lecture-based style that is teacher focused. PBL has an objective to develop life long learning along with professional reasoning skills. It bridges the theory-practice gap so it promotes learning effectively. It can be more efficient in use of resources than tutoring but leads to the same increases in student scores in concept inventory tests. Key features of PBL are that groups of students undertake tasks together, facilitated by an academic; tasks vary in length; and self-direction; reflection and review are important.

Woods[6] contrasts the difference between PBL and "subject based" (traditional) learning as being: in PBL students must learn what they need to solve a problem, while in subject based learning they must learn what the teacher thinks they need to solve a problem. The latter leads to duplication (as usually the teacher assumes the students know little) and presentation of information in a sequence that makes sense to the teacher, but not necessarily to the student. Or conversely, the teacher assumes the students know more than they do, and so the student will be unable to learn due to gaps in their knowledge. Woods also claims PBL is far more effective as it motivates students and embeds knowledge in a context that helps the student to integrate new knowledge with old. A key skill of the teacher is to select problems that are complex enough to challenge the students but simple enough to allow "layering" to occur by choosing more complex problems in later years.

One of the pioneer experiments with PBL commenced in the early 70's at the University of Aalborg in Denmark. A review of the first twenty years was published in 1994 ([8]). Engineering programs were restructured with group work comprising 50% of each semester using either project-based learning ("the know-how") or problem-based learning ("the know-why"). Lectures were used in the remainder to develop knowledge related to the projects and general curriculum. The aim of this restructure was to ensure the graduates obtained the latest up-to-date engineering knowledge by setting real-world, open-ended problems. Where traditional courses produce graduates suited to working in a stable environment "applying standard solutions to known problems", PBL produces graduates suited to a complex dynamic environment where they can solve "unenvisaged problems of the future".

Evaluation of PBL

Duch and Groh[9] describe assessment of PBL courses by student feedback sessions several times per semester as well as the instructor's analysis of what worked well. This type of approach can be used equally well with traditional lectures. However it fails to identify if PBL has achieved superior outcomes for students compared to traditional lectures.

Aalborg University's use of PBL in engineering programs was audited by the Danish government. The university was found to be "the most effective of the Danish engineering educational institutions". The engineering programs were evaluated by "international panels, ...external examinators, alumnus and their employers and undergraduate and graduate stu-

Copyright © 2005, Australasian Association for Engineering Education

dents". The evaluation mechanism was written surveys (except for the panels) with a return rate of 50% or higher. The findings conclusively showed that PBL can develop graduate capabilities effectively. The alumni were characterized as "adaptable...with strong qualities in problem-solving, communication and general technical knowledge". They were also noted to have weaknesses, namely a "lower load of specialist knowledge and methodology".

Some other interesting results were also given. The graduate students favourite semester was 7 (of 9): none chose semester 1 or 2, attributed to lack of technical knowledge, scientific tools and a feeling among freshmen that "the demands in the project work [were] uncertain". Only 13% of alumni judged the weight of taught courses insufficient compared to project work, showing that 50% project work was very satisfactory. Aalborg programs also had a significantly lower drop-out rate and higher pass rates than traditional engineering programs at another university, suggesting the students were more engaged in their learning.

A "modest" student survey was developed by Ahlfeldt et al ([10]) from a larger US "National Survey of Student Engagement (2000 [11])". The Ahlfedlt survey evaluates three areas, collaborative learning, cognitive complexity and gains in personal skills. These are then summed to give an overall "engagement score". The survey was used to evaluate a wide range of classes in various years and various disciplines, including classes that used PBL. The results showed that significantly higher engagement scores were achieved in more senior classes, smaller classes, classes using PBL, and arts more than science classes.

Our Study

We decided to use this survey to test whether our first year students were demonstrating a different level of engagement in the project-based courses. We were able to compare Sustainable Engineering and a similar course in the Civil and Infrastructure Engineering program, Environmental Principles for Sustainable Design, with two more traditional courses, Biochemical and Materials Engineering and Mathematics.

Sustainable Engineering – a PBL course

The first year Chemical Engineering PBL course, PROC 2074, Sustainable Engineering, is a core course that begins development of graduate capabilities essential to Chemical Engineers. These include teamwork, communication skills, problem solving and decision making, sustainability, project management and personal and professional development. In 2005, the course was re-structured to allow for a stronger focus on problem based learning (PBL). A major component of the course was a research oriented group project. The project topic was a feasibility study on alternative applications of grape pomace, a by-product from the wine making industry.

The course is run with approximately 6 contact hours per week. The large class of 40 students was divided into two for workshops, with parallel sessions running for each group, in a flat floor room designed for group activities. Within each group, the students were split up into sub groups of four students, to undertake the various activities throughout the semester. Approximately 40% of their time was spent on the project while the remainder of the time focused on the other activities designed to develop the graduate attributes detailed above.

It was considered an important part of curriculum design that all the activities were directly linked into the project and were designed and scheduled to provide students with the fundamental skills required to undertake the project. For example, the section on project manage-

Copyright © 2005, Australasian Association for Engineering Education

ment focused on the use of project management tools such as Gantt charts, WBS, and PERT diagrams and was run early in the semester. The concept of sustainability and the triple bottom line was directly linked to the theme of the project, and addressed later in the project when the students needed to choose the "best" solution. No formal exam was held for this course; the assessment was based on the activities conducted throughout the semester.

The course was carefully tailored to develop concepts that link it to other courses. For example, the topics covering the role of a chemical engineer and the introduction to the chemical engineering industry mesh well with the next PBL course to be taught in second semester, called Introduction to Chemical Engineering Design. Similarly, the topic on occupational health and safety is a link to the laboratory courses in first, second and third year. Teamwork, presentation and reporting skills (both oral and written) are further developed in many later courses, including the pinnacle of the program, the major courses in the final year, experimental research and design projects.

Environmental Principles for Sustainable Design – a PBL course

In Sustainable Design, civil and environmental students worked on an investigation and design project. They were asked to consider four proposals for the enhancement of visitor facilities at a major city park. These options ranged from a simple information shelter through café, restaurant, convention/conference centre to camping facilities. They were led through a process made up of the following steps:

- Research
- Problem definition, including the development of selection criteria
- Alternative generation
- Analysis
- Decision making and recommendation

In parallel with the project tutorials, students received a lecture series that took them through the development of environmental principles and legislation from the 1970s onwards, including specific case studies.

Student engagement in these two components of the course (project and lecture series) was examined.

Biochemical and Materials Engineering – a traditional, lecture based course

The Materials component of the course PROC 2075 Biochemical and Materials Engineering is predominantly taught using teacher focused lectures. Lectures are given two hours per week in a lecture theatre and the various topics are presented to the students using PowerPoint display facilities. Assessment for this part of the course consists of a mid semester test, final exam, assignment and presentation based around the assignment.

Mathematics – a lecture based course

The first year Chemical Engineering lecture based maths course, MATH2128, is taught through a mixture of lectures, supervised problem-based practice classes, online tests and quizzes, and self-help tutorials. The course aims to consolidate and extend students' knowledge in areas to which they have had varying degrees of exposure, such as differential and integral calculus, and to provide an introduction to unfamiliar topics such as vectors, differential equations and multivariable calculus. To accommodate the wide variation in mathematical

Copyright © 2005, Australasian Association for Engineering Education

background, there is attention to basic mathematical skills, e.g. arithmetic, algebraic manipulation, elementary geometry and trigonometry.

The lectures aim to be reasonably informal, driven by plenty of examples and with frequent opportunity for the class to work on examples together with the lecturer.

Weekly practice classes give students the opportunity to interact with their peers and tutors as they solve a mixture of straightforward and more challenging problems. The challenging problems are often topical, and where possible relate directly to examples from chemical engineering. These problems generally involve moving from a verbal description, to a mathematical formulation, to a solution that combines a number of different elements from the current study topic (and possibly other topics).

Common misconceptions and gaps in mathematical background are identified by the weekly online WebLearn tests. All of the tests are multiple choice or true/false, and marking takes place within five minutes, giving the students quick feedback. Students do these tests in their own time and our experience is that the results correlate well with their marks from the supervised practice classes.

Self help is available to the students in the form of online WebLearn quizzes (which can be done as many times as desired), self-help tutorial sheets and homework problems set from the textbook. The mathematics department runs a daily drop-in centre at which queries relating to any of self-help activities listed above may be discussed with the rostered tutor.

Summary of the Data Collection

Student engagement data were collected from the following cohorts:
- Sustainable Engineering (PBL) – project only
- Sustainable Design (civil and environmental PBL course) – lectures and project
- Materials Engineering
- Mathematics

Results and Discussion

The student engagement survey was administered to RMIT chemical and civil engineering students in various courses to measure the level of student engagement. The survey was used to explore the following hypotheses:

1. Student engagement is higher in classes taught using PBL than traditional lectures.

2. PBL is effective in any engineering field.

3. The variation in student engagement is lower in classes taught using PBL than traditional lectures

4. Traditional lectures can be enhanced by using interactive techniques and score higher levels of engagement

Copyright © 2005, Australasian Association for Engineering Education

Table 1: Student engagement survey results for 1st year classes (mean ± std. de v.)

Discipline	Chem Eng			Civil Eng	
Approach	Sust Eng PBL	Mats Eng Lectures	Maths Lectures	Sust Des PBL	Sust Des Lectures
Sample size	26	38	43	19	19
Co-operative Learning Variable	10.8 ±1.2	9.0±2.7	8.8±2.9	10.7±1.5	7.7±2.6
Cognitive Level Variable	13.7±1.5	12.6±2.6	14.2±2.1	13.7±2.3	11.9±2.2
Personal Skills Variable	14.1±2.7	13.2±3.3	14.0±3.0	14.5±2.6	11.8±3.4
Total Engagement Score	38.6±4.4	34.8±7.3	37.0±6.2	38.9±4.8	31.4±6.9

The results show a significantly higher engagement score for the first year classes conducted with PBL, compared to traditional lectures in another course. This is statistically significant at $p<0.05$ comparing Sustainable Engineering with Materials Engineering ($p=0.006$) and Sustainable Design project with the matching lectures ($p=0.0002$).

This is in agreement with results reported by Ahlfedlt et al (2005) that courses with a higher level of PBL scored higher on engagement score. Through this higher level of engagement, we might expect that students will develop those graduate attributes of interest.

The results show no significant difference between disciplines, which is also consistent with the findings of Ahlfedlt et al.

The average standard deviation for PBL classes was 2.0 and for engineering lectures was 2.6, suggesting that student engagement in PBL classes is consistently higher. This suggests more learning occurs across the whole student cohort, in particular, in the lower performing part of the class.

The results show that the maths class run using a more traditional lecture format also scores well with engagement. This may be attributed to the innovative approach used in this course, and shows that a traditional lecture format can also deliver significantly higher engagement scores than teacher focused lectures, by use of techniques such as weekly class quizzes, online tests, and tutorial type exercises during lectures.

Student feedback data

Meetings are held twice per teaching semester between Chemical Engineering staff and student representatives consider any issues of concern to students. The comments on the course *Sustainable Engineering* were "... not a lot of class time yet; not enough to get teeth into yet – where is it going?" during the first meeting early in the semester and no comments during the second meeting later in the semester, due to the apology of all first year reps. This is consistent with the reports by Aalborg postgraduates that as freshmen they found "the demands in the project work [were] uncertain".

Conclusions

In 2005, chemical engineering at RMIT introduced a new curriculum with a strong commitment to project-based learning. This paper describes an initial study to examine student engagement in the first of these project-based courses. It demonstrates that students are more

Copyright © 2005, Australasian Association for Engineering Education

engaged than in a traditional lecture-based course taken by the same students. Similar results were demonstrated for a cohort of civil and environmental engineering students.

Interestingly, a lecture-based mathematics course taken by the chemical engineering students showed almost the same level of engagement as the project-based course. This is a testament to the active learning strategies put in place in that course.

In second semester, students will tackle a more challenging project in chemical engineering, namely the design of a portion of a natural gas separation plant. It remains to be seen if the same level of engagement is maintained.

References

1. Hadgraft, R. & Muir, P., Defining Graduate Capabilities for Chemical Engineers at RMIT, *Australasian Assoc. for Eng Educ. Conference*, 2003, RMIT University.
2. Institution of Engineers, Australia, *Accreditation Manual*, Canberra, http://www.ieaust.org.au/membership/res/downloads/AccredManual.pdf (accessed 7 April 2003)
3. RMIT University, *Teaching and Learning Strategy 2000-2002: Quality learning tailored for students and clients, for employment, leadership and career-long learning*, http://prodmams.rmit.edu.au/uc5amdhhtdye1.pdf (accessed 14 April 2003)
4. Bowden, J., & Marton, F., The university of learning: beyond quality and competence in higher education. London: Kogan Page, 1998.
5. Faculty of Engineering, *Renewal of the Bachelor of Engineering 2002-2004 Project Plan*, (internal document), RMIT, Melbourne, 2002.
6. Woods, D., *How to get the most out of problem-based learning*, Donald R. Woods, Waterdown, Canada.
7. Hadgraft, R. G. & Prpic, J. K., The key dimensions of Problem Based Learning, *11th Annual Conference and Convention of the Australasian Association for Engineering Education*, Adelaide, 26-29 Sep, 1999.
8. Kjersdam, F. and S.Enemark (1994) *The Aalborg Experiment*, Aalborg University Press, Aalborg, Denmark
9. Duch, B.J. & S.E.Groh (2001) *Assessment Strategies in a problem-based learning course* in *The Power of Problem-Based Learning* (Ed) B.J.Duch, S.E.Groh, D.E.Allen, Stylus Publishing, Sterling, VI, USA.
10. Ahlfeldt, S., Mehta, S., Sellnow, T. (2005) Measurement and analysis of student engagement in university classes where varying levels of PBL methods of instruction are in use, *Higher Education Research and Development*, V24, 1, Feb 2005, pp 5-20.
11. National Survey of Student Engagement. (2000). *Improving the college experience: National benchmarks of effective educational practice*. Bloomington, IN: Indiana University Center for Postsecondary Research and Planning.

Biographies

MARGARET JOLLANDS joined RMIT in 1996, and lectures in polymers and mechanical engineering courses. She has a Graduate Diploma in Education, RMIT 2001, and won the inaugural RMIT University 2000 Distinguished Teaching Award in Higher Education. Her research interests include how to engage students with learning in the classroom.

ROGER HADGRAFT is Teaching and Learning Director in the School of Civil and Chemical Engineering at RMIT University. He has been working on problem-based learning issues since 1991 and has implemented significant curriculum change using project-based learning at both Monash University and RMIT. He is a civil engineer with interests in hydrologic modelling, knowledge management and engineering education.

LIAM WARD (bio to follow).

Copyright © 2005, Australasian Association for Engineering Education

IAN GRUNDY received his Ph.D. in Applied Mathematics from the University of Adelaide in 1987. Since 1990 he has been a lecturer in mathematics at RMIT University, and has been mainly involved with teaching first and second-year engineering mathematics. For the last ten or so years, he has been the first-year service mathematics coordinator. He is interested in Mathematics Education, Fluid Mechanics and Evolutionary Computing.

Copyright © 2005, Australasian Association for Engineering Education