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An evaluation of a project-based learning initiative in engineering education

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An evaluation of a project-based learning initiative in engineering education

Project-based learning is a well-known methodology for engineering design education due to a number of benefits it is claimed to offer. This paper presents the initial offering of a first-year engineering PBL unit at Griffith University in Australia. An evaluation of student perceptions of the unit revealed that students generally enjoyed the experience, with the oral presentation aspect receiving the lowest satisfaction rating. There was no significant difference in the ratings between any demographic grouping suggesting that all students were able to participate in, and experience, the unit in essentially the same way. The best aspects of the unit and those aspects needing improvement were similar to the findings of other investigations documented in the literature. It is proposed that future offerings of the unit will reduce the number of design projects from three to two per semester, and will attempt more sophisticated individualisation of marks for group work activities.

Keywords: project-based learning; engineering education; evaluation

1. Introduction

Project-based learning (PBL) is a well-known methodology for engineering design education and many case studies are documented in the literature (Dym *et al.* 2005, Prince and Felder 2006). However, it has been noted that much of this literature is essentially course descriptions presenting the implementation details of individual courses, and that more serious evaluation is harder to find (Helle *et al.* 2006), and that additional research is needed (Lima *et al.* 2007). This paper presents the initial offering of a new first-year unit '1006ENG Design and Professional Skills' at Griffith University in Australia. The unit aims to provide an introduction to engineering design and professional practice through a project-based approach to problem solving. In addition to the details of the unit format and assessment, the findings of an evaluation into the student perceptions of this unit are presented, along with proposed changes for future offerings of the unit.

2. Project-based learning

It is noted that a wide variety of practices with varying purposes are subsumed under the banner of PBL (Helle *et al.* 2006), and that the differences between these various instances of PBL can make it difficult to assess what is and what isn't PBL (Thomas 2000). However, in the literature (Frank *et al.* 2003, Helle *et al.* 2006, Macías-Guarasa *et al.* 2006, Prince and Felder 2006) there can be found a general consensus that PBL incorporates the following elements:

- solution of a problem or completion of a task requiring students to complete a number of educational activities that drive learning;
- generally, students work in teams to complete a project;
- the project is non-trivial and often multidisciplinary in nature, requiring work over an extended period of time;
- normally, the project involves the development of a concrete artefact – a design, a model, a thesis, a computer simulation, etc.;
- the culmination of the project is often a written report and/or oral presentation describing the project methods and the final product; and
- teaching staff take an advisory rather than authoritarian role.

Many benefits for student learning are claimed for PBL (Thomas 2000, Frank *et al.* 2003, Mills and Treagust 2003, Doppelt 2005, Helle *et al.* 2006, Macías-Guarasa *et al.* 2006), including:

- experience and development of teamwork;
- self-motivation and student ownership of the problem, solution and learning;
- development of self-regulation, agency, commitment and competence;
- experience of problem solving and the design process;
- exposure to the multi-disciplinary and systems nature of problems;
- experience of authentic problems and professional practices;

- development of reflective skills;
- development of written, oral and other communication skills and
- coping with incomplete and imprecise information.

Design is considered one of the central functions of engineering practice, hence it is desirable that students gain practice in developing effective design solutions under realistic conditions of incomplete data and potentially conflicting constraints (Mills and Treagust 2003, Dym *et al.* 2005). However, many engineering curricula are still predominantly based on an 'engineering science' model that is heavy on mathematical analysis, and where design, if present, is often segregated (Dym *et al.* 2005). Additionally, the format of much engineering teaching remains 'chalk and talk' in large, single-discipline classes, which is not a particularly active form of learning, nor is it reflective of professional engineering practice (Mills and Treagust 2003). Engineering programs have traditionally been taught in a deductive mode, from the bottom up, from component to system – the instructor first addresses the required underpinning theory and methods for mathematical analysis, followed by textbook problems and, perhaps, finally real-world applications (Frank *et al.* 2003, Prince and Felder 2006). Many of the characteristics and benefits of PBL make it a relevant pedagogical strategy in engineering education – realistic problems can be posed; design can be the vehicle for learning; and an inductive mode of teaching can be employed. Additionally, it is noted that student work on projects is a long-standing and common form of learning activity in primary and secondary schools in many countries, hence it is a teaching and learning method that will be familiar to many commencing university students (Thomas 2000, Mills and Treagust 2003).

3. The Griffith Engineering School PBL initiative

The Griffith School of Engineering offers a three-year Bachelor of Engineering Technology (BEngTech) and a four-year Bachelor of Engineering (BEng) degree at its Nathan and Gold Coast campuses, in Queensland, Australia. Advanced studies and double degrees are also offered. The BEng programs are accredited by the Australian engineering professional body Engineers Australia. Those programs offered on the Gold Coast campus have recently been restructured to facilitate a common first-year for the four specialist majors on offer:

- Civil Engineering;
- Electrical and Electronic Engineering;
- Mechatronic Engineering; and
- Sport and Biomedical Engineering.

A new first-year unit '1006ENG Design and Professional Skills' has been created in the revised structure. The unit aims to provide an introduction to engineering design and professional practice through a project-based approach to problem solving, and seeks to realise the benefits of PBL for student learning identified in the literature above.

It is recommended that PBL incorporate opportunities for feedback and revision as student work progresses, as well as multiple high-stakes/for-marks assessment activities where students must articulate the basis of their design solutions – including reports and presentations (Helle *et al.* 2006). The unit comprises an underpinning lecture series, design work including group project activities, an individual Computer Aided Drawing (CAD) exercise and an oral presentation. The group project activities are assessed through three group design projects, requiring written 'preliminary' and 'final' design reports. The use of a series of 'mini' design projects to enhance PBL is noted in the literature (Frank *et al.* 2003, Macías-Guarasa *et al.* 2006). The CAD component and the oral presentation are each related to one of the three projects. The students are given the choice of which of the projects they use as the basis for the CAD exercise, and (as a group) which project they present. While the oral presentation is group-based, individual marks are awarded. Table 1 presents a summary of the assessment and the percentage allocation of marks to each assessment item.

Table 1. Summary of unit assessment items.

Assessment item	Marks weighting	Description
Prelim. design report (Project 1)	3	Group mark
Final design report (Project 1)	22	Group mark + SAPA
Prelim. design report (Project 2)	3	Group mark
Final design report (Project 2)	22	Group mark + SAPA
Prelim. design report (Project 3)	3	Group mark
Final design report (Project 3)	22	Group mark + SAPA
CAD drawings (on Project 1, 2 or 3)	15	Individual mark
Oral presentation (on Project 1, 2 or 3)	10	Group delivery, but individual mark

The three design projects are:

(1) Mechanical Design Project – Objective: to design and build a mouse-trap powered car to race five metres in the shortest possible time;

(2) Electrical/Electronics Design Project – Objective: to design and build a linear accelerator (motor) that will accelerate a mass through a sequential series of coil stages; and

(3) Civil Design Project – Objective: to design and construct a geometric scale model of an urban development site for the 'Leprechaun Village Corporation'.

To facilitate student engagement in each of the group design projects, students were allowed to choose their own groups, and asked to provide self-and-peer assessment (SAPA) ratings for each group member for the final design report of each project. SAPA is a proven method for assessment of teamwork processes, including in design-based settings (Tucker *et al.* 2009). The intention of SAPA assessment mark was to differentiate between the contributions provided by each group member. Students were provided with a rubric guide for making their SAPA ratings: ratings were out of 10, with up to 2 marks awarded for participation/attendance, 4 marks for the quantity of work produced and 4 marks for perceived quality of the work. In this SAPA implementation, provision of ratings by students was optional, and non-submission of a rating was taken as an equal rating for group members. The individualised design report mark was calculated using equation 1.

$$\text{Final Report Mark} \times \frac{\text{Total Peer Assessment Mark (for student in question)}}{\text{Total Peer Assessment Mark (for best performing student)}} \quad (1)$$

4. The investigation and results

As part of an evaluation of the initial offering of the PBL unit, it was decided to undertake a survey of enrolled students to assess their prior experiences related to PBL and their perceptions of the conduct of 1006ENG. The questionnaire given in the Appendix was developed to gather this data. An independent experienced member of the teaching staff was invited to review the questionnaire, and based on their feedback it was refined to enhance its face validity. Approval to conduct the survey was obtained from the Griffith University Human Research Ethics Committee (GUHREC). The questionnaire was administered during the final week of the semester. As required by the GUHREC approval, the questionnaire was anonymous and voluntary.

Table 2 presents a summary of the demographic and related characteristics of the respondent student group. Where the corresponding information is known about the entire student population enrolled in the unit, this is also presented. Where the sum of sample frequencies is less than 72, it signifies one or more non-responses in that category. Table 3 presents the mean and associated standard deviation for student responses to the questionnaire scale items. The respondent open-ended comments were analysed to identify themes. Common themes were tallied and the ranked results are presented in Table 4.

Table 2. Demographic and related characteristics of respondent student group.

	Sample	Population	Significance / etc.
Number of respondents	72	237	30.4 %
1.1 Mean age (Standard deviation)	20.97 (4.9)	—	
1.2 Gender			
Female	8	18	Fisher’s exact test
Male	63	219	*p* > 0.33
1.3 Enrolled program			
1310 Engineering	50	176	
1318 Engineering Technology	6	19	
1320 Engineering with Advanced Studies	6	13	Fisher’s exact test
1321 Engineering / Science	3	6	*p* > 0.35
1323 Engineering / Information Technology	1	2	
1078 Engineering / Business	3	9	
Other	0	12	
1.4 Intended study major			
Civil	52	—	
Electrical / Electronic	5	—	
Mechatronic	10	—	
Sports / Biomedical	1	—	
Other	4	—	
1.5 Median entrance score (OP)	10	—	
2.1 Previous experience with PBL		—	
Yes	29	—	42.7 %
No	33	—	48.5 %
Not sure	6	—	8.8 %

Table 3. Mean student rating and standard deviation for questionnaire scale items.

Questionnaire item	Mean	SD
2.2 Do you enjoy working in groups/teams?	3.43	0.93
2.3 Do you enjoy giving oral presentations?	2.65	1.21
3.1 Did you understand what you needed to do for the design project assignments?	3.51	0.86
3.2 Were you able to find the information you needed to complete the design project assignments?	3.72	0.84
3.3 Did your group work well together on all design project assignments?	3.36	1.24

3.4 Was your group presentation successful?	3.53	0.93
3.5 Were you satisfied with the designs produced by your group?	3.67	0.95
3.6 Overall, was 1006ENG an enjoyable learning experience?	3.46	0.96
3.7 Did 1006ENG increase your knowledge of engineering design & professional skills?	3.63	0.98

Table 4. Themes from student open-ended comments ranked by frequency of occurrence.

4. Best aspects	Freq.	5. Needs improvement	Freq.
Group work	18	More time on project work	11
Hands on / practical	16	More instruction on CAD	11
No exam	11	Better explanation of expectations	10
Projects enjoyable	7	Less emphasis on group marks	5
Less lectures	6	Smaller groups	4
CAD	5	More background on principles behind projects	4
Mousetrap car	4	More even participation on groups	3
Variety of projects	4	Faster feedback	3
Meeting new peers	4	Spread assessment due dates better	3
Helpful staff	3	More consistency in marking	2
Exposure to engineering work	3	Course more organised	2
Group shared workload	2	Support for design report writing	2
Independent studies	2	More lectures	2
Linear accelerator	1	Guidelines for group operation	1
Regular assessment	1	More feedback	1
Problem solving	1	More help from demonstrators	1
Appropriate difficulty	1	Choice in projects	1
Group motivated me to work	1	Relate projects better to discipline areas	1
Develop team skills	1	More scope for variation in designs	1
Presentation	1	Fewer projects	1
Workload	1	Workload too heavy	1
Presentation skills	1	Blind peer review not 'blind'	1
Good resources	1	More general support for students	1
Project guides comprehensive	1	Minimise/drop lectures	1
Civil project	1	Prize for best mousetrap racer	1
Engineering reporting	1	Activities to meet peers prior to group selection	1
Design work	1		

5. Discussion

The total number of responses received was 72 out of a unit enrolment population of 237, yielding an overall response rate of 30.4 percent. Some demographic information was available for the overall enrolled unit population, as well as collected as part of the survey, including gender and enrolled program. This permitted a comparison between the respondent sample and the overall enrolled unit population on these demographic dimensions based on the exact, two-sided version of Fisher's test. For both gender (Fisher's exact test; $p > 0.33$) and enrolled program (Fisher's exact test; $p > 0.35$), there was no significant difference in the proportions of responses between the respondent sample and the overall enrolled unit population. So, although the overall response rate was modest, the significant absolute number of respondents and the good match between the respondent sample and the enrolled unit population based on known demographic characteristics reduces the risk of non-respondent bias, and suggests that we can have confidence in drawing more general inferences about the overall enrolled group from the respondent data.

The comparatively low mean age of respondents suggests that the class enrolment is dominated by conventional entry students coming directly from, or shortly following, completion of secondary school. The relatively low proportion of female students (both in the respondent group and the total unit enrolment) is consistent with the low proportion of female students in Australian undergraduate engineering programs generally, and recent experience at Griffith University (Stewart 2007). The responses to questionnaire item 2.1 regarding students' prior experiences with PBL indicate that a majority of students have not previously been exposed to a PBL learning environment, suggesting that guidance on the aims and processes of PBL will be essential.

Table 3 summarises students' responses to the scale item questions. Many of the mean ratings are similar. In a similar investigation of PBL in an 'early years' (first and second year of a program) context, the overall mean rating for enjoyment reported by students was 3.79 (out of 5) (Edward 2004) – similar to the 3.46 observed here for item 3.6. A measure of the statistical significance of the results in Table 3 is given by computing a mean confidence interval (based on assuming a normal distribution of responses) for the ratings. The mean 99 percent confidence interval for the scale item ratings is +/- 0.3. On this basis, the mean rating for the scale item 2.3 'Do you enjoy giving oral presentations?' is clearly significantly lower than all other items. Historically, it has been observed that many engineering students have an aversion for public speaking (Beer 2002), and in another first-year design unit, essentially the same results as seen here were also observed – students found the experience very enjoyable and disliked oral presentations the most (Hanesian and Perna 1999). Although the mean rating for scale item 2.3 was the lowest ranked, it was also observed that the rating for the related scale item 3.4 'Was your group presentation successful?' was significantly higher, suggesting that the arrangements for the oral presentation in this unit assisted with student acceptance of oral presentation as a learning and assessment activity.

A one-way analysis of variance (ANOVA) comparison of the mean ratings for each of the questionnaire scale items against all of the questionnaire categorical response groups (gender, enrolled program, intended study major and prior PBL experience) was performed. In all cases, Levene's test of the homogeneity of variance indicated no significant difference in the variance of scale item ratings between categorical groups, and hence that a standard ANOVA test could be validly employed. The subsequent ANOVA results revealed no significant differences in mean scale item ratings between categorical response groups, and in many cases the ratings were essentially identical between groups. This suggests that all students were able to participate in, and experienced, the unit in essentially the same way, regardless of gender, enrolled program, previous experience with PBL, etc. Previous investigations have also concluded that PBL/design projects can be a supportive learning environment for diverse engineering student cohorts, allowing minority groups (Lumsdaine *et al.* 1999), including female students (Du and Kolmos 2009) to participate equitably.

A number of the ‘best aspects’ and ‘needs improvement’ themes reported by students in Table 4 are also reported in the literature on student evaluations of PBL, including positive aspects of PBL:

- students perceived teamwork as valuable (Dym *et al.* 2005);
- use of ‘real world’ practical applications (Mills and Treagust 2003, Edward 2004);
- assessment moved from examination to project work;
- exposure to aspects of professional engineering and engineering work; and
- experiencing helpful teaching and support staff (Frank *et al.* 2003).

And, for negative aspects:

- high time demands of project work;
- issues with group members who did not pull their weight (Mills and Treagust 2003);
- need for an introduction to, and preparation for, teamwork; and
- need for instruction on engineering/design report writing (Frank *et al.* 2003).

It is recognised that much engineering design is conducted in a team environment with complex socio-technical dimensions (Dym *et al.* 2005). In group-based activities where membership is self-selected, group selection may be based on pre-existing friendship groups; but this was not always the case – suggested here by the fact that ‘meeting new peers’ was identified as one of the best aspects of the unit. There are a number of the identified themes related to working in groups, reflecting the multi-dimensional nature of group work. If the various group work threads listed under the 'needs improvement' heading were collected together, group work would then simultaneously be the most frequently reported positive and negative theme in the open-ended student comments. This result is perhaps also reflected in the largest standard deviation for a questionnaire scale item mean rating occurring for the item 3.3 'Did your group work well together on all design project assignments?'.

6. Proposed changes

Overall, the initial offering of 1006ENG was considered to be successful in achieving its aims and intended student learning outcomes. Based on the experiences gained from the first offering of the new PBL unit and the evaluation documented here, a number of changes to the delivery and assessment of the unit have been proposed.

The number of design projects included in the PBL unit will be reduced from three to two, with a corresponding reduction in the proportion of unit marks assigned to group-based assessment from 75 to 50 percent. It has previously been suggested that students can realistically handle two projects per semester before they begin to lose continuity between unit material and different design projects/applications (Kellar et al. 2000). It is hoped that this change will directly address a number of the 'needs improvement' issues identified by students in Table 4, including 'Less emphasis on group marks', 'More background on principles behind projects'; 'Faster feedback', 'Spread assessment due dates better', 'Fewer projects' and 'Workload too heavy'.

As noted previously, both in the student comments here and in the literature, issues relating to group work often become key concerns in PBL (Frank *et al.* 2003, Mills and Treagust 2003). Where the artefact(s) of group work and/or group processes are to be assessed in PBL, a challenge arises in how to fairly rate the contribution of each team member? (Helle *et al.* 2006) The current SAPA system employed provides some moderation of individual marks based on potentially scaling back the score of group members who are rated a making a lesser contribution to the group's output. However, group members who are rated as higher performing by the SAPA system are not currently rewarded with a mark above that awarded overall to the group design reports. This could be a problem where there is a large disparity in aims, expectations or abilities between group members, and there isn't a mechanism for equitably resolving this tension. It is planned to revise the SAPA system to fairly allow for both positive and negative individualisation of marks for group-based assessment results. Potentially instructive case studies of SAPA in a design education context do exist in the literature; for example, the individualisation of assessment scores via an online SAPA tool in the context of an architectural design studio class (Tucker *et al.* 2009).

The feedback from students on the oral presentation component was ambiguous; scale item 2.3 'Do you enjoy giving oral presentations?' received the lowest rating, but scale item 3.4 'Was your group presentation successful?' was rated significantly higher. This is one element of the unit that we will continue to monitor closely.

7. Conclusion

This paper presents the initial offering of a new first-year unit '1006ENG Design and Professional Skills' at Griffith University in Australia. The unit aims to provide an introduction to engineering design and professional practice through a project-based approach to problem solving. An evaluation of student perceptions of the unit revealed that students generally enjoyed the experience, with the oral presentation aspect receiving the lowest satisfaction rating. There was no significant difference in the ratings between any demographic grouping (including gender), suggesting that all students were able to participate in, and experience, the unit in essentially the same way. The best aspects of the unit and those aspects needing improvement, as reported by students, were similar to the findings of other investigations documented in the literature. For future offerings of the unit it has been proposed to reduce the number of design projects from three to two per semester, and to attempt more sophisticated individualisation of marks for group work activities. The investigation methods documented here provide one approach for the evaluation of PBL activities in engineering education.

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Appendix 1006ENG Design & Professional Skills – PBL Questionnaire

1.1 Please state your age in years AND months

1.2 Please indicate your gender

1.3 Please indicate your enrolled program code

1.4 Please indicate your intended study major

1.5 Please indicate your Griffith tertiary entrance score

2.1 Before commencing 1006ENG, had you previously participated in PBL activities? [Y/N/?]

2.2 Do you enjoy working in groups/teams? [1-5]

2.3 Do you enjoy giving oral presentations? [1-5]

3.1 Did you understand what you needed to do for the design project assignments? [1-5]

3.2 Were you able to find the information you needed to complete the design project assignments? [1-5]

3.3 Did your group work well together on all design project assignments? [1-5]

3.4 Was your group presentation successful? [1-5]

3.5 Were you satisfied with the designs produced by your group? [1-5]

3.6 Overall, was 1006ENG an enjoyable learning experience? [1-5]

3.7 Did 1006ENG increase your knowledge of engineering design & professional skills? [1-5]

4. What were the best aspects of 1006ENG? [Free text comment]

5. What could be improved about 1006ENG? [Free text comment]

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