A first year project-based learning programme – the first iteration

Karl Dahm[a] and Allan Anderson[a].
School of Engineering & Advanced Technology, Massey University, Palmerston North 4222, New Zealand[a],
Corresponding Author Email: K.L.Dahm@massey.ac.nz

Structured abstract

CONTEXT
A recent re-design of the Bachelor of Engineering (BE) programme at our institution put in place a heavy emphasis on project-based learning (PjBL). For first year entrants into the BE programme, one quarter of their course (30 credits out of 120) involves project papers (each paper is worth 15 credits). This project-based "spine" was a considerable departure from the previous degree structure and numerous challenges were posed during the creation of the PjBL papers.

PURPOSE OR GOAL
This paper will document challenges and difficulties experienced in using the PjBL approach for teaching and explain the rationale behind changes to the PjBL papers from their introduction to the subsequent year.

APPROACH
An extensive de-brief followed the first implementation of the project-based papers. Based on this information changes were made to the subsequent iteration. Additional guidance was drawn from pedagogical literature. The debrief exercise was repeated after each iteration. Informal feedback on the value of the PjBL approach was also collected.

These changes were accompanied by changes in other taught papers in the course. The links between the technical knowledge from and project work were strengthened in particular by "mini-projects" within the PjBL spine.

ACTUAL OR ANTICIPATED OUTCOMES
Findings from the debriefing sessions were summarised as evidence for the efficacy of changes made to the PjBL papers. Data from student performance and pass rates suggested that the changes made were effective in increasing student learning and/or student engagement. An ongoing challenge for the PjBL papers remains the link between taught content and project activities.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY
Project-based learning requires continuous improvement and development of courses to match desired learning outcomes with those achieved. Support for the learning outcomes is increasingly found in informal observations and feedback gained outside the assessed portions of the PjBL papers – information which can be very difficult to collect.

KEYWORDS
Project-based learning

Introduction

In late 2009 the School of Engineering & Advanced Technology at Massey University began a programme to re-design the structure of the Bachelor of Engineering (BE) degree. This redesign process comprised a strategic rationalisation of majors in conjunction with a review of the curriculum to:

- Enhance student experience and engagement, particularly in the first two years of study
- Improve retention rates
- Reduce overlap and duplication in teaching
- Reduce the number of papers offered.
- Increase class sizes
- Reduce gaps between industry expectations and graduate capabilities
- Increase cohesion within the curricula so that topics and learning flow

Compared to the previous curriculum, the new curriculum places a strong emphasis on the application of contextual knowledge through professional practice and the ability to solve complex engineering problems. These attributes are reinforced by two project-based learning (PjBL) papers in each of the first two years (25% of the curriculum). In these papers students work in teams to solve engineering (technical) problems aligned with industry and the wider society. The remaining 75% of the curriculum (six papers per year) is focused on embedding the sciences and engineering fundamentals. The new structure was introduced for first year students in February 2012 simultaneously over two campuses.

What is project-based learning?

The distinction between problem-based learning (PBL) and project-based learning (PjBL) is a subtle one. Prince and Felder (2006) provided the following definition:

> *Project-based learning begins with an assignment to carry out one or more tasks that lead to the production of a final product—a design, a model, a device or a computer simulation. The culmination of the project is normally a written and/or oral report summarising the procedure used to produce the product and presenting the outcome.*

Although this could equally apply to PBL as well as PjBL, especially in the engineering subject areas. PBLE (2003) gives further examples of definitions of PjBL.

Both PBL and PjBL are examples of what are commonly termed ‘active learning’ approaches according to Michael (2006). Roberts (2006) describes the most basic level of active learning as the “active engagement” of a learner in the learning process in contrast to the passive involvement assumed for traditional teaching strategies.

The premise for active learning is often summarised by the ‘Learning Pyramid’ which suggests that the more active the learning experience, the better the learning outcomes (usually denoted by “retention”) are (a potted history and numerous examples of the Learning Pyramid are given by Metiri Group (2008)). Even if the pyramid is absent, its rationale may be stated aphoristically, for example from CDIO (2004):

> *Students remember less than a fourth of what they hear and only about half of what they see and hear.*

Despite its widespread use, several authors have demonstrated that the pyramid itself is not based on any sound evidence (for example Booth (2011), Lalley & Miller (2007), Metiri Group (2008)). Other authors (for example Kirschner et al (2006) and Mayer (2004)) have demonstrated that active learning is not necessarily better than traditional (guided) teaching methods. Mayer (2004) for instance showed that pure discovery learning was detrimental in three separate subjects and summarised the findings as follows:

Instead of depending solely on learning by doing or learning by discussion, the most genuine approach to constructivist learning is learning by thinking. Methods that rely on doing or discussing should be judged not on how much doing or discussing is involved but rather on the degree to which they promote appropriate cognitive processing. Guidance, structure, and focused goals should not be ignored. This is the consistent and clear lesson of decade after decade of research on the effects of discovery methods.

Despite any concerns about what the definition of PjBL is, project based learning has seen widespread adoption in the engineering education (see for example Graham (2010), Graham and Crawley (2010) and Harris (2002)). While the literature shows the importance of cognitive engagement and structured guidance for active learning approaches, there remains a strong tendency to focus purely on the project being carried out.

PjBL in the first year of study

The desired learning outcomes for the two first year PjBL papers – Engineering Practice 1 (EngPrac1) and Engineering Practice 2 (EngPrac2) are listed in Tables 1 and 2 respectively. In both papers the students work in teams to create potential solutions for a single large project. In the first semester EngPrac1 sees the students working on the Engineers without Borders Challenge. This requires discussion of contextual topics such as ethics and professionalism as well as sustainability. The main output for this project is a written report and teaching staff from the Communications & Media department (Massey University) were utilised to help students produce a high quality of written communication.

In the second semester, EngPrac2 requires the students to develop scenarios and concepts for the year 2070 based on their own research into socioeconomic, population, environmental, resource and technological drivers. The emphasis for this project is on creativity and visual communication. Accordingly students were given basic instruction in

Table 1. Learning outcomes for EngPrac1 – Engineers Without Borders Challenge

1	Apply science and engineering principles to the solution of a complex engineering problem - where complexity is defined by the social, environment and economic context.
2	Clearly define a problem, recognising uncertainty and creative thinking in the approach to solving a problem and consequently discuss potential solutions and articulate final recommendations.
3	Recognise the need for experimental enquiry and demonstrate a survey of print and electronic literature.
4	Explain a system, its behaviour, it elements and its interactions.
5	Explain one's personal knowledge, skills and attitudes and identify one's learning style and motivation for continued self-education.
6	Demonstrate one's professional ethics, integrity, responsibility and behaviour when working with one's peers.
7	Practice written and oral communication styles.
8	Explain the roles and responsibilities of engineers and discuss the relevance of these roles and responsibilities to the solution of engineering problems within societal and cultural settings.
9	Recognise the basic inputs and processes required for project management and define the key elements of the design process.

Table 2. Learning outcomes for EngPrac2 – Creative Solutions for 2070.

1	Apply science and engineering principles to the solution of a complex engineering problem - where complexity is defined by incomplete and ambiguous information.
2	Interpret a problem demonstrating analysis of uncertainty and creative thinking in the approach to solving a problem.
3	Interpret and synthesise relevant information and data from written and oral sources.
4	Use a systems thinking approach to define the problem.
5	Recognise self-reflection to increase awareness of one's personal skills and attributes.
6	Design an effective team and demonstrate its successful operation.
7	Practice electronic/multimedia and graphical communication styles.
8	Use project management tools to plan and manage activities and apply the design process to a relatively simple project.

visual design techniques (utilising Industrial Design staff from the College of Creative Arts, Massey University), computer-aided design and the use of other graphical software packages.

In both papers a range of assessment methods were used and comprised both individual and group assessments. A group of engineering academics acted as supervisors to the groups and also acted as assessors for some of the student work. Each paper made extensive use of Stream (Massey University's Moodle-based VLE) with a site for each paper as well as an Engineering Practice "meta-site" that contained information relating to facilitating concepts and skills for engineering projects.

Collection of feedback

These PjBL papers marked a dramatic departure from previous first year teaching practice for the BE degree at Massey University. A range of mechanisms were used to collect feedback about the papers from both student and staff perspectives. Student feedback was gathered during targeted interviews of students at the end of their first year as well as from comments raised through staff-student liaison meetings. A debrief meeting involving all co-ordinators and supervisors of the two papers was conducted to get staff perspectives on the papers.

To date this feedback exercise has been carried out at the end of 2012 (the first year for the new BE programme structure). In 2013 the process has not yet been completed with the student interviews and second semester debrief meetings not yet conducted.

Feedback-based improvements in the project papers

Once the un-structured raw feedback was collected, issues were identified and sorted into the following broad categories:

- co-ordination – how the administration of the papers was handled
- the project – issues related to the project topic itself
- enablers – taught content introduced for students to apply to the project
- assessment – the means by which student learning was assessed.

The authors then identified what, if any, actions were required for each issue and prioritised them based on the impact on attainment of learning outcomes and students' cognitive engagement in project activities. The highest priority changes are described below.

Co-ordination – Promoting effective supervision

During the 2012 EngPrac1 and EngPrac2 papers students received inconsistent information from different staff involved in the paper. Supervisors also felt that they were not sufficiently informed about the project as a whole and found it difficult to keep track of where the students should be at each weekly meeting. This was in spite of the distribution of detailed week-by-week information to supervisors as well as the ready availability of supporting documents in the papers' Stream site.

These problems were addressed in two main ways. Firstly, the key information about the overall aims and requirements for the paper (the EWB challenge in EngPrac1 and the creation of scenarios for 2070 in EngPrac2) were introduced to supervisors and students at the same time. Secondly, supervisors were sent weekly e-mails before their team meetings reminding them of what the students were expected to have achieved (when applicable), be doing in that week as well as what was coming up in the following weeks. This e-mail "newsletter" received positive feedback from the supervision team as it enabled them to keep track of where their teams should be without imposing additional demands on their time (as would have been the case with weekly supervisor meetings).

Coordination – group formation

Webb et al (1998) showed that the heterogeneity of groups (in terms of ability) could dramatically affect learning outcomes, and that it is impossible to simultaneously optimise the learning of high-ability and low-ability students. Hadim & Esche (2002) also reported that allowing engineering students to select groups themselves introduced significant imbalance in the groups and affected fair evaluation of both individual contributions and overall team performance. With this in mind, different strategies were used for forming project teams in EngPrac1 and EngPrac2.

In 2012 students were assigned to groups in EngPrac1 at random, while the groups in EngPrac2 were "streamed" based on the students' performance in EngPrac1. In EngPrac1 international students were distributed throughout the groups so that they worked with domestic students. This was intended to give a better initial experience for the international students, offering them the opportunity to interact with and learn from domestic students.

This structure (with international students distributed throughout the teams) gave poor results for the international students. Of 44 international students enrolled in EngPrac1 in 2012, 9 failed the paper - a failure rate of ~20% compared to the failure rate for domestic students of ~3% (3 students in 93). Exit interviews with the international students (both successful and unsuccessful) found difficulties in communicating led many to feel (and in some cases to actually be) excluded from their teams. Attempts to provide targeted support to the international students had the unintended consequence of taking them away from their groups and therefore increasing this sense of exclusion as the international students needed to catch up on team activities they had missed.

In 2013 students were again randomly assigned to teams for EngPrac1 but with separate teams for international and domestic students. The main intention with this change was to better allow targeted support of the international students. The failure rate for international students in EngPrac1 in 2013 approximately halved to 11% (3 students failing out of 28) while the failure rate for domestic students remained relatively unchanged (2 students failing out of 89 – approximately 2% failure rate).

Enablers – written communication

The written communication aspect of EngPrac1 (2012) comprised a major component of the course with students submitting four written assignments (worth 20% of the overall paper assessment) and a final report (worth 20% of the overall assessment with marks received both for technical content and report structure). While this emphasis on written communication yielded final reports of very high quality, students felt the in-class workload was high and perceived the main learning outcome of the paper to be written communication.

In 2013 the written communication assessments were changed so that they were integrated better into the project activities, as summarised in Table 3. The intention of this change was to keep the focus of the students on their project, and to reduce workload as the communications assessments also aided in the completion of the project itself.

Based on staff feedback gathered for the 2013 offering of EngPrac1, supervisors appreciated the timeliness of the communications staff's support and felt that the students appreciated the way in which the communications aspect was organised (student feedback has yet to be gathered). A comparison of the communication marks for the EngPrac1 final report (for structure of the final report, rather than technical content) is shown in Figure 1. A clear increase in mark for the majority of groups can be seen suggesting that the change in structure may have helped the students apply the communications skill they developed during EngPrac1. The difference in the overall marks however were not statistically significant to p=0.05 (although this result was heavily influenced by the single outlier group in the 2013 cohort with a very low mark).

Assessment – balancing individual and group assessment

In both EngPrac1 and EngPrac2 there was a 50-50 split between individual and group-based assessments. In the context of PjBL, the pertinent question is how individual assessments can be extracted from project work performed in groups. Assigning individual grades based on group work is not a new problem, an extensive literature survey of methods for obtaining such individual grades has been conducted by Lejk et al (1996).

In 2012 a peer assessment (PA) exercise (see below) was conducted in EngPrac1 but used purely as a formative assessment to identify dysfunctional teams. All students received the group mark for the group assessments. In 2012 EngPrac2 team function was assessed using panel interviews. The absence of a peer evaluation exercise was seen by students as a major shortcoming – with students who did not pull their weight getting the same grades as harder-working team mates.

Table 3. Individual communications assessments for 2013 offering of EngPrac1.

Exercise 1	Analysis of research process (due week 3). This served to help the students engage with the information retrieval workshops they attended and as an early identifier for any students who might need additional support.
Exercise 2:	Technical memo (due week 5). This was addressed to the team supervisor and was written to accompany the project charter/management plan (which was the basis of team interviews conducted in week 5).
Exercise 3:	Annotated bibliography and summaries (due week 9). Each student prepared an annotated bibliography of one key piece of information they retrieved. This was intended to coincide with the students putting together the literature review for their report.
Exercise 4:	Report introduction (due week 11). As the groups were starting to complete their project this assessment was tied in with tutorials on putting together larger reports and was intended to assess their skills in summarising their work to date.

Timings are based on 12 weeks teaching.

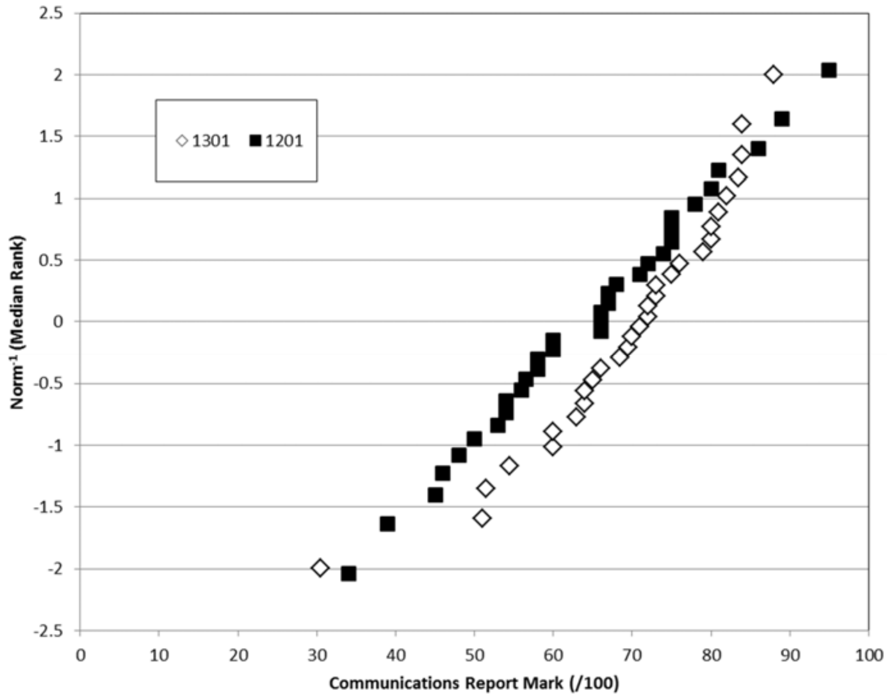

Figure 1. Normal probability plots of the raw group communication marks received for final reports in EngPrac1 for 2012 (1201) and 2013 (1301).

This reaction echoed statements by Roberts (2006) that the main problem in group assessment is perceived (by both staff and students) to be that of the “free-rider” or “slacker” – a student who contributes little but still benefits from the shared group mark. Roberts (2006) suggests that PA within groups is the most fair and stable method of distinguishing individual contributions. Kaufman et al (2000) reported that an “auto-rating” PA system (based on that developed at RMIT by Brown (1995)) reduced student complaints about “free-riders”. Kaufman et al (2000) restricted their assessment to:

responsibility of performance and not academic ability or percentage contribution to project

and showed that concerns about students conspiring to give each other the same grades, inflated self-assessment and prejudice (based on ethnicity or gender) were not borne-out by the results.

In 2013, a spreadsheet-based PA system was used for EngPrac1 using PA forms based on those developed by Brown (1995) and Kaufman et al (2000) (but with a reduced number of possibilities) using non-numeric grades. Individual team members’ marks for group assessments were modified using a non-linear peer adjustment factor (SPA) reported by Willey (2006):

$$SPA = \sqrt{\frac{\text{sum of ratings for student}}{\text{average of all ratings received by all team members}}}$$

Willey et al (2009) also reported that the ratings the students gave themselves (termed SAPA – the self-assessment – to peer assessment ratio):

$$SAPA = \sqrt{\frac{\text{self rating for student}}{\text{average of ratings for student by other team members}}}$$

could be used as a formative feedback tool to aid students' abilities in self-reflection as well as allowing the identification of so-called "saboteurs" (those students who deliberately submit dishonest assessments).

To look at how the PA was used by the teams, the differences between maximum and minimum SPA scores within each team was calculated. For both campuses the distribution in SPA "spread" was very similar with one third of teams having a spread <0.1, and a further third having a spread between 0.1 and 0.2. The remaining third of teams were apparently more dysfunctional with SPA spreads between 0.2 and 0.4 (and in one exceptional case 0.55). Independent evidence of poorly performing individuals corresponded with teams with large SPA spreads. From this it can be concluded that many groups felt that a single team mark awarded to all team members would not be a fair assessment of individual performance during the project. Student feedback about the PA exercise has not yet been gathered.

An examination of self-assessment (SAPA) scores showed that the number of students under-rating themselves (SAPA<SPA) was slightly larger than the number of students over-rating themselves (SAPA>SPA). Only three students fell into the category of potential saboteurs (those students according to Willet et al (2009) with SPA<0.85 and SAPA>1.5).

Concluding remarks

The introduction of PjBL papers in a first year engineering course posed numerous challenges. Feedback gathered was instrumental identifying areas where the experience of both students and staff could be improved. A well-documented process for implementing changes based on the feedback was used to change the 2013 offerings of the papers. For the four main changes implemented (and reported in this paper) the following conclusions can be drawn.

A lightweight means of keeping supervisors informed about expected progress and activities of students was used that received favourable feedback from staff.

Although a causal link cannot be guaranteed, changes to the way international students were grouped in EngPrac1 coincided with an approximate halving of failure rates for international students in that paper.

Improving the link between communication teaching and project activities was successful in increasing the report writing scores for most teams.

An auto-rating peer assessment (PA) exercise provided clear evidence that many students did not feel that a single group mark would fairly reflect individual performance.

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