Developing student teamwork and communication skills using multi-course project-based learning

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Structured abstract

BACKGROUND
As part of a restructure of the engineering programs offered by the University of Ballarat a need was identified to better develop the teamwork and communication skills of students. It is recognised in industry that new graduates, while strong in skills such as mechanics and design, are often weak in teamwork and communication skills. A project-based learning (PBL) exercise was developed that incorporated three first year courses being Design & Drafting, Statics, and Engineering in Practice, so that students would be exposed to a practical design-and-build project set in a team environment, while also practicing team and communication theory. The semester long project required teams of 4 to 5 students to plan, research and then build a cantilever truss while learning the advantages of teamwork.

PURPOSE
It is possible to introduce effective teamwork and communication skills early in the engineering program through the use of project or problem-based learning; encouraged by industry and a review of the engineering program, the combined course PBL exercise was implemented in the first year to introduce students early in their academic life to organised teamwork.

DESIGN/METHOD
Students learned communication and team theory and strategies in class, followed this up with skill-based tutorials and applied themselves to a design and build project. New theory and instruction was implemented that allowed and encouraged teams to keep track of their work through setting agendas and recording minutes of meetings until the final report was submitted. Staff held team review meetings during the semester, another innovation, to gauge student progress and to aid in corrective action for dysfunctional teams. Teams were required to give a presentation to the student cohort prior to destructive testing of their projects. A previous PBL exercise had been focussed solely on one subject and it was decided that by integrating several courses into the one project that students would gain a wider understanding of the usefulness of teamwork in attaining a common goal.

RESULTS
Students gained a greater awareness of the importance of teamwork and particularly communication skills, evidenced via meeting minutes created by student teams and reviewed by teaching staff, and team interviews conducted during the semester to gauge performance and aid in the guidance of poorly functioning teams. Teaching staff gained a firmer understanding of student team dynamics and were able to develop clearer and more equitable tools for teamwork assessment.

CONCLUSIONS
Despite being introduced at an introductory level, the semester results showed that students could gain a solid start in understanding the value of teamwork. Results of the combined course exercise showed steady improvement in the years since its implementation when compared to the results of a previous single course PBL exercise. Communication, as a skill in its own right, was developed as an important tool.

KEYWORDS
Teamwork, communication, project-based learning.

Introduction

It is generally accepted that individual engineering academics are continually searching for ways to renew or update how they teach engineering, and to find new and exciting ways to test the knowledge of their students. However changes to the overall structure of the engineering degree course, or the program, have been slow. In his book "Teaching Engineering, All you need to know about engineering education but were afraid to ask" Peter Goodhew (2010) refers to a 1918 paper sponsored by the Carnegie Foundation that describes the then state of engineering education, and laments that little has changed in 95 years. He contends that the teaching of engineers will not be significantly changed for the better until theory and practice can be taught simultaneously.

Bandura (1977) proposed that in order to change behaviour effectively, that is to learn, students must be exposed to multiple sources of information. Together, vicarious experience, verbal persuasion, performance accomplishment and emotional arousal are effective at increasing self-efficacy expectations and, by extension, behaviour change. It has long been recognised that effective learning involves both practising component skills and integrated skills to draw components together to face more challenging, realistic problems (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011). This reference describes engineering education and recognises that the practices to create effective learning experiences concentrate on Affective, Meta-cognitive and Cognitive areas, which correlate closely with Bandura's Vicarious experience (Meta-cognitive), Performance accomplishment and Verbal persuasion (Cognitive) and Emotional arousal (Affective).

A group of people bring together not only their own skills and knowledge, but the dynamic synergy to achieve a collective goal. Social cognitive theory expands on an individual's self-efficacy and extends it to collective efficacy, and how a group will function as a unit (Bandura, 2000). Just as individual accomplishment and self-efficacy can be altered by integrated forms of learning, so too can collective efficacy, resulting in more motivated teams that are able to overcome difficult obstacles to produce greater accomplishments.

When specifically examining student work teams, it has been found that collective efficacy is closely related to team cohesion and to its performance (Lent, Schmidt, & Schmidt, 2006). To the engineering educator this may all seem self-evident, but to schools, departments and universities as a whole it seems less so. Universities can be slow to change and engineering programs may often be inertially challenged for a decade or more. People do not live or work alone, but continually interact with others, so why do so many university courses, or subjects, treat students in isolation? Group work, or team work, is a method of bringing new skills and learning experiences to students without the attendant pain of forcing large-scale change through the University's Academic board.

A teaching method that can successfully bring together theory and practice, both individual and in a team environment, is the Problem or Project-Based Learning exercise (PBL). Among universities that have seriously integrated PBL into their curriculum is Aalborg University in Denmark (Goodhew, 2010; Litzinger et al., 2011) in which team-based work and PBL forms the core of their learning in solving complex problems. This method produces results: when compared by employer groups against another technical university, Aalborg is clearly superior in several criteria, including people and project management skills and innovation and creativity (Litzinger et al., 2011).

The uptake of PBL into university courses in Australia is slow in some instances, but those who have been involved with its implementation recognise the advantages. Hadgraft (1998) described PBL as an active learning strategy that more creative organisations use to provide people-oriented solutions, and that universities would do well to emulate.

The need for change

Until recently, much of the undergraduate engineering program at the University of Ballarat was taught in the traditional manner of skills based learning within individual courses. Each subject, or course, was a mostly isolated unit within the overall program and eight courses per year were completed by students until all of the prescribed credit points for the program were completed. While some teamwork was included, this mostly involved experimental practical work, mostly for the sake of expediency. For example a practical exercise for Statics would involve breaking up the student cohort into groups of six for the duration of the laboratory work. The students then may, or may not, complete the report as a team effort. As such, students conducted little team-based project work and any project work actually undertaken was almost wholly conducted in their final year, and this was mostly as individual tasks.

In recent years, work began within the engineering faculty to retool the engineering programs and this included all three disciplines of Civil, Mechanical and Mining engineering. Benchmarking was conducted against other institutions, Ballarat staff met with industrial leaders from the region, and forums were held with student groups. The university has an active Industry Advisory Group drawn from leaders of local industry and their advice helped focus the direction that the programs would take. A common theme that came from all this input was the relevance between teaching engineering skills and their application in the real world. Communication skills were a dominant theme, for while graduates were seen as technically proficient, they were judged less so on the skills that allowed them to work in a team environment. To this end it was felt that more of the “soft” skills of teamwork and communication should be emphasised. Ballarat is not the only Australian university to implement PBL into the curriculum as explained by Mills and Treagust (2003) with the University of South Australia, Curtin University, CQUniversity, RMIT and Monash among those having embraced the concept (eg Hadgraft et al, 2004).

The first year at Ballarat is common to all disciplines, with discipline specific courses taking effect from second year. While this first year commonality was to remain, it was decided that much could still be done to bring more real world relevance to what were mostly skills based courses. To this end the integration of teamwork and semester long projects into the curriculum became a focal point. Peer interaction is an important part of learning and teammates can often provide immediate assistance to individuals with questions (Webb, 1989). It can certainly be timelier than elaboration by teaching staff, which is almost always after the fact.

The new curriculum integrated PBL into both semesters of first year in a scaffolded way that provided diminishing support to teams at each semester, leading into higher level projects into second year and closely followed Hadgraft’s *Key attributes of a problem-based learning environment* (2005). It was seen as the best way to expose students to team work environments and collective problem solving while giving them the communication and team management skills that industry demanded.

The addition of PBL was not driven by the work done in other institutions, but by the unique needs at Ballarat highlighted by investigations carried out to support program changes. It was also recognised that any changes should incorporate best teaching practice in engineering education for the benefit of Ballarat students, rather than copying the work of others. Some may look on the integration of PBL as an exercise in reducing the workload of teaching staff; however PBL was not used as a method of teaching and marking expediency; this was a happy accident rather than a planned occurrence.

Project outline

The project was conducted across three courses within the first semester of the first year. While the project required the use of theory to solve a specific problem, it highlighted the use of a team-based approach to bring together a wide variety of skills from different courses.

The aim of the work was not so much to be aligned with what other institutions were doing, but to provide a learning exercise, structured in such a way as to meet identified gaps in student learning while being introduced so that theory could be combined with practical aspects to further reinforce that learning.

The basic requirement of the project for first semester was a design and build exercise for a very specific problem. The problem changed each year to give repeating students something new to look at and to allow staff some variation each year. The course coordinators would meet before the start of semester to discuss the project, decide on the weighting that it would have in each course and what each expected from their own students.

One coordinator would be responsible for assigning students to teams. Time constraints meant that exhaustively matching individual skills to teams through tests (Fitzpatrick & Askin, 2005), while considered, could not be accomplished ahead of the teaching semester. Students were assigned to teams randomly, and while this is not an optimal method (Sahin, 2011), it was felt that it would create a better chance of having more functional teams.

Past team selection practice with single-course teamwork had been to allow students to choose their own teams. While this lessens staff workload it was found to create teams of friends which then left outsiders, especially international students, feeling left out and alone. It was felt that grouping students into heterogeneous, rather than homogeneous teams would result in increased fairness for all and that students with high ability would be able to assist low-ability students, while not being disadvantaged themselves. Studies have shown that this can be the case (Webb, Nemer, & Chizhik, 1998).

The students were assigned to teams of five or six for the duration of the semester and were typically a mix of domestic and international. Teams were given a report template to use and team meetings were the responsibility of each team to organise and it was a requirement that these meetings would be minuted.

With regard to the distribution of final marks for the semester, the teams were self-regulating. In this they were given guidance by staff and a set of rules to follow. If it was agreed by all students in a team at the end of semester that each individual had submitted an even amount of work to the team effort then all members would receive the same mark. If however, one or more members had contributed significantly less than the others, those members would receive a lesser mark. All members were required to agree to the final mark distribution and sign the final report before it was submitted. If a disagreement arose, this would be arbitrated by one of the course lecturers prior to the submission of the final report. Passengers in a team are always possible of course, but only if the team allows it to occur. The consensus among students, however, clearly conveyed in small group discussion during tutorial classes, seems to be that this state of affairs is not acceptable and a fair grade for fair work is what is sought.

Once students had been placed into teams and swapped contact information with their teammates, they were given the semester project in the form of a clearly defined problem. In 2013 this was in the form of a gantry, such as that shown in Figure 1, which was required to support a minimum mass of 20 kg from its free end and was itself supported by two offset hard points. The load was 750 mm from the lower support and the entire structure could only be constructed from wood and glue and weigh no more than 400 grams. The project for 2012 was a bridge that was to span a gap of 1200 mm, to be constructed of wood and glue with a maximum weight of 400 gram. The minimum load was again a mass of 20 kg, centrally loaded. Teams may either use the labs as workshop space to build and test their structures or they may do it at home. In either case all testing is documented and quite often photographed, for the final report. At semester's end the structures were tested, firstly to the 20 kg load requirement and then to destruction.

The destructive testing of their work, attended by all students, became an informal competition. A carnival atmosphere of sorts, but with order and steel-capped boots. It certainly seemed a fitting culmination of their semester's work.

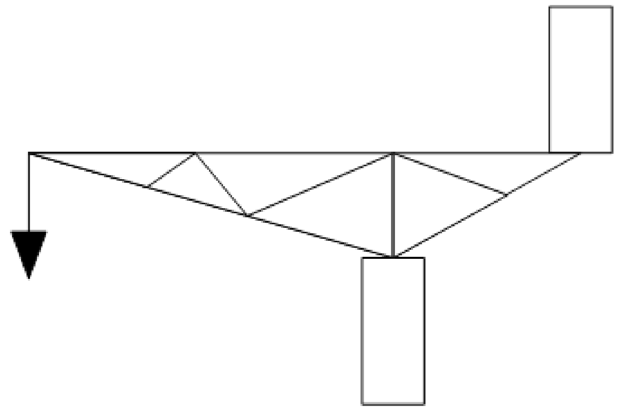

Figure 1: Example of the 2013 student team project

Methodology

The project was designed as a first year, first semester, PBL exercise specifically for student teamwork. It was intended to be as flexible as possible in its execution and could be embedded into two or three courses running within first semester, although typically it included three. Initially this included the courses Design & Drafting, Statics, and Engineering Materials. Students would use the skills taught in Drafting to produce 2D drawings, using AutoCAD, correctly dimensioned component and assembly drawings as a minimum, calculate the forces and stresses within the members of their truss design from their Statics theory and utilise basic testing techniques to aid in the selection of wood and glue as taught in Materials.

In addition to the core skills of each course, the students were given instruction in team and personal management. Guidance in the writing of reports and the referencing of information sources was stressed as important information by all course lecturers. The teams were informed of the specific aspects of the final report that would be graded for each course and how much that contributed toward the total coursework. Typically the final report counted 15–20% of the total mark for any one course.

The teams were also to conduct some preliminary research into the design as part of the report and to develop some concepts from which to continue. This would be discussed as a general part of the report and added to its completeness, but was not specific to any course grade.

Not only were the individual requirements of the three courses to be complied with, but the report was to be a coherent document presented in a professional manner. To aid this, the teams were instructed to use a standard document template consisting of coversheet, table of contents and sub-headings that were to be modified as they saw fit. At the end of semester each team submitted a final report and that was then passed between the various course lecturers for marking, each lecturer taking from the report what was required for the fulfilment of their respective course.

As part of the scaffolding applied to the project, students attended lectures in team communication methodology, systems thinking, decision making, introductory project management including timing plans and information management using the book “Engineering Your Future: an Australasian Guide” by Dowling, Carew and Hadgraft (2012) was used as a text. Lectures were reinforced by tutorial exercises in report writing, formatting, basic research skills and referencing, in addition to the skills taught in Statics and Drafting. Students were assessed in their use of Microsoft Office, particularly in their report formatting and also in their knowledge of referencing and the avoidance of plagiarism.

Team progress

It was inevitable that there would be dysfunctional teams, groups of people who could not seem to work with others and effectively worked in isolation and produced work toward the team effort in an assembly line manner rather than a coordinated effort. Some individuals never seemed to be able to find their teams and as late as week 10 had not begun any work, and this was despite the fact that all of the students were studying the same courses at the same time. Such lone rangers did poorly at marking time. However these examples were very much in the minority and most teams were able to produce work ranging from satisfactory to outstanding.

The teams were formed during class time in week 1 of the semester and typically consisted of 4 – 5 students. With most students being unknown to each other, they then spent some time getting to know their fellow teammates and swapping contact information. Laboratory tours were organised with lecturers and tutors and, early in the semester, teams underwent a workshop safety exercise as lab induction. During this exercise, students were instructed in the use of basic hand tools and the types of machine tools that they would need during the semester to complete their projects. Marking out, sawing, cutting and drilling are common exercises. Students wore personal protective equipment and each team completed a formal written safety analysis prior to work beginning. Once completed, students could then use the workshop with minimal supervision.

Results

The first combined course semester long PBL exercise was run in 2010 and involved the courses of Design & Drafting and Materials. Students who had in previous years done group work were to be henceforth only to be referred to as *teams*. This was aimed at fostering a sense of competitive spirit among the students and to focus them on contributing toward a combined effort rather than individuals in collaboration. However, team organisation was less than ideal and late enrolment of international students caused disruption because of the piecemeal nature of their inclusion into already existing teams. Some teams struggled to gain traction and, despite the efforts of teaching staff, never seemed to be able to organise properly. On the day of destructive testing one team presented a bridge with the glue still wet which promptly fell apart under its own weight.

For 2011, the same two courses were involved. More tutorial time was devoted to team organisation in Materials and students were instructed in the use of team meeting minutes to help them track their own progress. A standard report template was used. This became the required report format with the minutes attached in an appendix.

Statics was included in the project for 2012, and while calculations were a necessity of reports for the previous two years, they were now much more in depth and full force and stress analysis of the truss was required. More effort was made to provide more in-depth explanation of referencing of information sources, expanded instruction on report writing and closer supervision of teams, mostly during tutorial classes.

2013 saw a major change with the implementation of new engineering programs. Materials was moved to the second semester and its place in first semester was taken by a new course Engineering in Practice 1. The new course introduced instructional sessions in report set-up and document formatting. Communication, including teamwork, was a theme of course theory and team management included the use of the meeting agenda in addition to the minutes. Team Review Meetings, held in weeks 7 or 8, are used to check team progress, team functionality and for student feedback. Each team was interviewed for a 20 – 30 minute period and questions cover topics on participation, contribution, meetings and coursework, including lessons learned. Students freely discuss the pros and cons of the project work and the coursework, including lecture material. Students within many teams made comment on their awareness of team and information management in aiding work progress and the importance of communication in teamwork.

Teams were also required to give a presentation on their project before the first year student body. Preparation and the presentation of this talk was also a team exercise.

To gain an understanding of how the PBL exercise improved student learning a review of results was undertaken. For the three years prior to its implementation, results were taken from Design & Drafting which had a design and build project based on student groups to build and test a wooden bridge. The three years 2007 – 2009 inclusive can provide a baseline for the combined course PBL exercise. These results are shown in Figure 2 and show an almost flat line of between 56 and 57%.

The results are the teams' final report mark, taken as an average over the entire course in percent. In 2010 the results showed a dip to just over 55%, but thereafter showed steady improvement in the team average result. The dip coincides with the beginning of the combined course PBL task and teaching staff agreed in the aftermath of the results that its implementation especially that of the teams as discussed above was less than ideal. This result was a disappointment but the decision was made to press on.

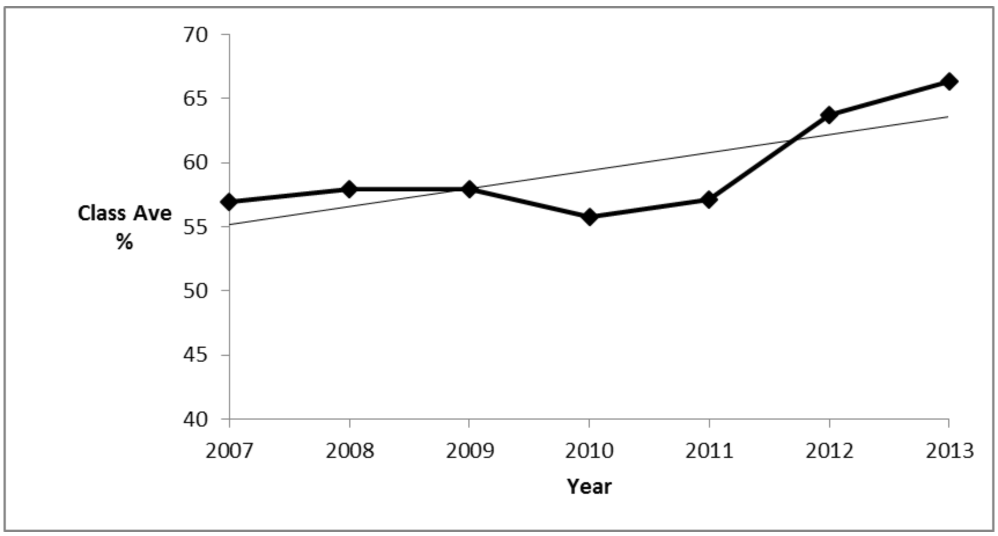

Figure 2: Average of team final report for the class

The following year did show improvement and in more than simply the average result figure. A marked improvement was seen in the quality and presentation of written work, with reports that were better organised and showed a higher degree of professionalism than anything previously seen. Part of this was in the student's use of a standardised report template but also improvements in the referencing of information sources, the use of appendices and the labelling of figures and tables. Other more subjective qualities were also evident, such as the better acceptance of more formalised meeting organisation and the taking of minutes to track team tasks and assignments. The level of research, while not expected to be high in the student's first semester, also improved.

Actual assessments against set criteria for certain skills used within the project are within the individual courses that are included in the PBL exercise. For some specific skills, such as those related to team communication for instance, these have only been introduced in the current year and little comparison can be made to previous years.

Conclusions

The combined course PBL exercise has been running for four years and is a flexible introductory learning exercise in teamwork that can be adapted for use with different courses. While the early result was sobering, the decision to persevere was borne out by the later results. Average team results showed a steady improvement to an average of over 66% over a previous single course PBL exercise in which results had remained flat-lined at approximately 56% over preceding years.

The value of the exercise was also seen in follow-up semesters and later years in the improved confidence that students were able to undertake further team and group work in other courses. In the case of most students it was also the first time that they had been required to stand before a large body of people to give a presentation.

More qualitative analysis is yet to be done and it is the authors' intention to continue to research the project through team and focus group interviews.

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