

Project and Team based Learning: An Integrated Approach to Engineering Education

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Abstract

The professional profile of the engineering profession has gone through significant changes during the past few decades. Traditional engineering education practices based on discipline based curricula and centred around conventional classroom lecturing and laboratory teaching are recognised to have reached their limits in preparing students for the diverse and cross-disciplinary tasks and work environments most of them will face as professionals. As a consequence, active learning approaches, using group and team based projects, have increased in engineering curricula world-wide.

With higher education, both locally and globally, subject to increasing financial and human resource constraints, resource-intensive teaching methods such as project based learning are threatened. However, the valuing of the opportunities provided by Project and Team Based Learning (PBL) is deeply embedded in the Engineering Education culture at the University of Auckland. Design and PBL courses in every year of the degree confront students with complex, multi-disciplinary issues and expose them to team-based, open-ended problem solving. Teaching these courses has also demonstrated however, that for all of its educational benefits, PBL creates new challenges for engineering educators in terms of high demands on teaching resources, project organisation and monitoring, and appropriate and fair assessment procedures.

This paper provides “best practice” exemplars of how these challenges are addressed in the PBL approach used in design and manufacturing systems courses at the University of Auckland. Examples are drawn from the introduction of PBL in first year design courses, through to final year industry-based projects. A range of tools and methods applied to optimise learning outcomes and to minimise some of the dangers and problems associated with team based and open-ended project work is presented. The effectiveness and benefits of the project based learning approach support the desirability of continuing to meet the inherent challenges.

Introduction

In the last few decades the complexity of current technological issues has risen dramatically, and the factual knowledge required to design, operate and control technological systems has risen almost exponentially. Increasingly, areas that in the past were the domain of highly specialised experts now require the input of more than one particular discipline in order to optimise processes, to integrate them into a broader systems context, or to gauge their technical and non-technological impacts on their environment such as a business system or a particular area of society. Professional engineers must not only be able to stay up to date with the latest developments in a particular discipline, but also communicate and collaborate with professionals from a range of disciplines from within and outside engineering.

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Tertiary and professional institutions worldwide have reacted to these challenges, and have developed new curricula and teaching methods to address these issues in the process of education of professional engineers. The U.S. Accreditation Board of Engineering and Engineering Technology (ABET) and other professional bodies such as the New Zealand Institution of Professional Engineers (IPENZ) not only require a range of socio-technological dimensions to be integrated in the curricula of undergraduate engineering degrees, but increasingly the focus of their accreditation procedures has been on evidence demonstrating the achievement of graduate capabilities (Cleland, 2004). The desired IPENZ Graduate profile (IPENZ, 2003), for example, includes competencies such as the ability to:

- Formulate and solve models that predict the behaviour of part or all of complex engineering systems
- Synthesise and demonstrate the efficacy of solutions to complex engineering problems
- Understand the limitations of the applicability of methods of design and analysis
- Function effectively in a team with the capacity to become a leader or manager
- Communicate effectively, write effective reports and design documentation, make oral presentations

The ability to cope with complex, diverse and multi-disciplinary engineering problems and systems has been specifically identified by IPENZ and other Washington Accord partners as an essential attribute for professional engineering graduates. In attempting to cover these diverse student outcomes in a coherent conceptual framework traditional classroom based teaching has been increasingly recognised as delivering students with deficiencies such as: the inability to link classroom concepts to the real world, poor understanding of the interrelationships between different disciplines (Sanderson & Millard, 1996), poor use of external knowledge sources and a lack of skill in the framing and solving of open-ended complex problems (Seidel, 2004).

Nature and Benefits of PBL

Since the early 1980s a multitude of educational approaches have emerged using Problem Based Learning principles. De Graaff and Kolmos (2003) suggested an “amazing diversity of educational practices” was evident in the application of problem based learning but identified that the essential characteristic of all was that the problem was the starting point of the learning process. Although the type of problem was dependent on the specific organisation, they recognised that problems were usually based on real-life situations which had been selected and edited to meet educational objectives and criteria. The range of applications was a continuum which went from very open, student-centred, interdisciplinary problems with the teacher acting as facilitator of the learning process through to well-defined, discipline-specific projects.

Learning via problem-based projects, hereafter referred to as project based learning (PBL), has been widely recommended and recognised as an appropriate and successful method for engineering education (De Graaff & Kolmos, 2003), (Dym et al, 2005), (IEAust, 1996).

Major strengths of this approach have been identified as:

- Experiential learning or more simply “Learning by doing” - implicit in PBL. Students are required to work collaboratively to define the problem, identify and acquire the skills and knowledge needed to solve it, and iteratively work towards an optimal solution. In so doing they are not only provided with immediate proof of the relevance of the theoretical knowledge they have been acquiring, but they are forced to draw on, and extend knowledge learned in one context to another. When

achievement and academic success act as the spur, students quickly take responsibility for their own and the group's learning.

- Enhanced motivation and interest in learning result in deep learning.
- Working in small groups or teams to a common goal allows the development of the co-operative skills highly valued by and necessary for the profession.

In particular, the common use of small groups for project based learning provides the opportunity to cover complex, systems-based topics in realistic task scenarios (Hung, Choi, & Chan, 2003), (Seidel, 2001) and enables the integration of non-technical factors in the learning process.

PBL in the Engineering curriculum at the University of Auckland

At the University of Auckland PBL is currently applied in a range of subjects. It is the main teaching approach used in engineering design courses at different levels throughout the curriculum (Seidel, 2004) and also applied in various courses offered in the manufacturing systems and technology management area (Seidel, 2001). Final year projects, which form the capstone of the curriculum in the majority of the engineering disciplines offered at Auckland, are also based on a PBL approach.

Projects play a vital role in providing students with a crucial attribute desired by industry for a newly graduated engineer: the ability to identify and define a problem, develop and evaluate alternative solutions, and effect one or more designs to solve the problem (Nicolai, 1998). At Auckland it is generally agreed that this attribute can only be developed by exposing students to the experience of open-ended problem solving which includes linking engineering science knowledge to complex, real-life design problems and projects. Apart from the 'hard' engineering and technical issues, these problem solving activities generally include a range of extra-disciplinary and 'soft' factors, such as economic, environmental, sustainability, manufacturability, ethical, health and safety, social and political considerations, in line with the ABET guidelines (ABET, 2004).

Engineering design has always played an important role in the four-year undergraduate engineering curriculum at the University of Auckland. At the Department of Mechanical Engineering, for example, design accounts for about 15% of the curriculum, and a PBL approach has been adopted in its design courses since the early 1990s (Anon., 1994). PBL is introduced in design classes in the first year for all engineering students, as it has been recognised that new entrants into the degree need to be familiarised with the overall scope and nature of professional engineering work, and in particular exposed to engineering design as one of the core competencies of the engineering profession. It is deemed important for students to understand and experience from the start that professional engineering work encompasses a much broader range of issues than covered in science or technology based courses such as thermodynamics, mechanics, and materials, which have a relatively narrow focus on a specific area of technological knowledge.

Year 1 students still have very limited knowledge of engineering science principles. The emphasis of design at this level is therefore mainly on generic, open-ended problem solving. (Seidel, 2004). A 'fun' design and build project is used to introduce PBL and teamwork at the end of the first semester design course. Students have to apply their engineering mechanics knowledge to create a truss bridge with the highest possible load bearing capacity over a given span. At the end of the course designs built by the student teams in the School's

laboratories are tested to determine yield and failure mode. The cornerstone design project in the second semester is based on a quite vaguely defined problem statement, which students first have to process through a problem definition phase into a formal product design specification. Then they are asked to apply creative techniques and design tools to create a comprehensive conceptual design proposal. The underlying theory, as well as recommendations for teamwork and project management, is provided in form of service lectures and comprehensive course handouts.

The real benefits of PBL can only be achieved by using project scenarios that are appropriate for the students' level of knowledge and experience. Therefore careful planning and integration of projects into the rest of the curriculum is necessary and new topics and aspects must be introduced in a logical and consistent way in order to prevent students from being seriously overburdened and confused. To achieve this a coherent 'design framework' has been developed in the Department of Mechanical Engineering. The framework is structured into the two main areas of 'Fundamentals of Engineering Design', covering topics such design process, communication in design, and CAD, and 'Engineering Design Applications', with the topics design of machine elements, integrated design and design of mechanical systems. The different elements and concepts in each topic area are allocated to the various design courses and projects within the Department's four-year curriculum, providing a good overview at which level of the programme each of the concepts and topics is introduced, and later on reviewed and/or extended (Seidel, 2004).

In the manufacturing systems area PBL was first introduced in 1995 in the elective course Industrial Engineering (Seidel, 2001). Students in groups of three to four were introduced to project tasks in industry, in conjunction with a limited number of supporting lectures. Typical projects include factory layout analysis, the design of assembly workplaces, analysis of manufacturing work flows and feasibility studies for the introduction of new technology. This new approach switched the emphasis of instruction from a broad and superficial classroom-based coverage of manufacturing to a more specific and focussed discussion of selected topics. Evaluation of the project-based approach revealed a renewed enthusiasm in the subject, and allowed the participants to experience the real world applications of their classroom learning (Seidel & Gunn, 1997). Encouraged by this success the PBL approach has also been adopted in the introductory paper into the subject with a much larger class roll. Here hypermedia-supported learning principles are used to create virtual projects in a virtual factory setup called InfoStation. Experiences with the InfoStation concept have been largely positive, and the approach has been continuously extended to create a virtual manufacturing company environment that simulates real life manufacturing situations within a range of different design, manufacturing and management courses (McCarthy, Seidel, & Tedford, 2004).

Final year projects form the capstone PBL experience in most of the engineering disciplines at Auckland. In Mechanical Engineering, projects are organised for pairs of students who generally either negotiate a topic or select one from a list of suggestions by one of the staff members in the Department. The course weighting of the project is higher than any other lecture course offered in the undergraduate curriculum, and therefore the scope of work covered during its more than 7 months duration is significant. Project topics vary depending on discipline and personal interest of students and supervising staff member, but they generally include a range of non-technical considerations in line with the ABET and IPENZ guidelines mentioned above (ABET, 2004), (IPENZ, 2003).

Implications and requirements of successful PBL

The educational outcomes of the various PBL activities at the University of Auckland have been overwhelmingly positive. This is documented by a broad range of indicators such as the quality of the project solutions submitted by students, by a large amount of student feedback that spans a period of more than a decade, and in particular through comments made by employers and former graduates, either during presentations of final year projects, or during discussions between staff and their industry contacts. However, over the years, it has also been realised there are some significant challenges associated with PBL, which are discussed in the following sections.

Resource Implications

One of the major challenges of PBL is the higher use of resources compared to traditional classroom based teaching. Due to the complexity and the variety of issues included in typical projects suitable for PBL, preparation time and efforts are significantly increased. Apart from the sourcing and formulation of the project task, a significant amount of work is required to specify appropriate project scope and objectives, determine assessment elements and criteria, and develop a project and team management framework for the project. All these aspects must be carefully designed and integrated and double-checked in order to achieve the expected learning outcomes and to avoid problems with overloading or confusing students. Project assessment, which includes marking of project reports and other student output, and the preparation of meaningful feedback and comments to students, is another aspect of PBL that requires more time, more care, and more experience than the marking of traditional examinations and assignments.

As PBL generally requires teamwork and/or small group tutoring, the issues of manageable class sizes (Seidel, 2001), availability of suitable tutorial rooms or laboratory space, and the availability of qualified and motivated staff and tutors with adequate communication skills need to be carefully considered. This is particularly important in the current climate of diminishing funding and increasing cost pressures of most teaching and research activities at Universities.

Setting Objectives and Assessment

Project objectives used in PBL need to be carefully designed in order to avoid overloading and confusing students. Objectives need to be communicated and discussed at project start to give students a guideline for their learning process. They also should be separated into 'practical' or 'technical' objectives (i.e. the ones that are directly related to the technical outcome of the project task, and learning objectives, which concentrate on the educational goals of the particular PBL exercise. Both aspects need to be covered by the assessment process, and students need to be reminded that they must provide evidence in their submissions that they achieved the educational goals of the project as well as a satisfactory technical solution to the design task.

Assessment process and criteria need to be carefully designed to match project and course objectives and to stimulate learning. Assessment procedures vary depending on the specific requirements of each project, taking the above factors into account and attempting to achieve an objective and balanced account of each student's abilities at the end of each PBL exercise. At Auckland a step-by-step approach to assessment, fitting the particular project task and

consisting of a number of complementary elements such as group design reports, individual workbooks and a group oral interview, has been found most beneficial. In team based projects, assessment procedures are integrated with the team management procedures discussed below in order to achieve a fair assessment and to prevent cheating and freeloading.

Project management

An important aspect of successful PBL is the project management infrastructure associated with the project work. The development of project management skills is an important spin-off of PBL. However, project management issues need to be carefully integrated into the project work, and monitored throughout project duration. The amount of project management support required and provided in handouts and course material and by the project organiser and tutors is dependent on the stage and the experience of the particular students. Generally an exact time frame with guided tutorials needs to be provided for first year students with little experience. In later stages a less pre-defined structure with more project management responsibility of students is appropriate, although it has been found that relatively close monitoring is necessary in projects which largely rely upon outside resources, such as industry based projects, or which extend over a whole semester or even longer. In those cases, it is beneficial to require students to develop a project proposal with formalised objectives and a project plan as one of the first parts of their project requirements.

Another issue arising from open-ended project work is the question of student workloads. This is particularly important as students tend either to take shortcuts or spend too much time on project. In particular in interesting, 'real-life' design projects, some students are so inspired by the project work that they tend to neglect all their other study requirements. To prevent this from happening the project scope and recommendations for total work hours spent on project need to be clearly communicated in the project handouts and discussions.

Quality control and student feedback

From the introduction of PBL in the early 1990s it was seen as extremely important to elicit formative feedback from students in order to monitor the effectiveness and quality of the PBL principles applied as perceived by the students, and to identify any problems that could not be directly observed and monitored in class or from student submissions. Different tools and approaches have applied over the years to receive the broadest possible and best quality feedback, ranging from a standard student feedback mechanism applied to all courses taught in the School, to more specialised formative feedback surveys which are conducted periodically in PBL courses. In these surveys detailed questions are posed for the students to answer. A particularly successful format has been to ask students to respond to specific questions under the two headings 'What I really liked about...' and 'If there was one thing I could change about this, it would be...'. Typical questions relate to the format and structure of the course, project content, course material, tutorial support, assessment and feedback process, and team work aspects.

Teamwork

As mentioned above, the ability to work in a team has been identified as one of the most important attributes that students are expected to develop during their undergraduate engineering degree course. Specific teamwork arrangements are based on the nature of a particular project, the level of students' experience and the particular examination

requirements set by the project organiser. The goal is always to achieve the main benefits of team work, which include the honing of good interpersonal communication skills, experience in dealing with conflicting views and dissent, practice in the division of work tasks and labour, and enhancement of the creative potential of team members (Denton, 1997).

An important element is the careful grouping of students into a fair mix of teams for each project. Over the years various options have been trialled to establish a team selection and team building process that maximises the opportunities for each student in each team to contribute to their team's development and to reach their personal potential. From observation during project tutorial sessions and from analysis of student feedback it has been found that generally this is best achieved if team selection is performed before the start of a project by the project organiser on the basis of ethnic, gender and enrolment status. Aim is to create an equal and within each team, a preferably diverse mix of these attributes. This is particularly important to avoid 'ghettoisation' of particular groups such as low performing or students with English as a second language (ESL), who in Auckland comprise about 1/3 of design classes. For these ESL students team work in a PBL environment is a prime opportunity for mixing with colleagues from different cultural backgrounds. However, the 'colourful mix' does not appear to work well in projects with team sizes of two: in this case it has been shown to be preferable to let students choose their own partners. This avoids direct personality clashes and enables students to take advantage of their partner's strengths. In this situation students generally choose partners who they know and have already collaborated with.

Cheating and Freeloading

One downside of team based learning is that some students attempt to take advantage of teamwork arrangements in order to get a 'free ride', or to avoid certain types of tasks, such as CAD modelling, literature research, data acquisition and analysis, or report writing. To eliminate these problems as much as possible, a range of tools such as confidential peer assessment, oral interviews and specific work and submission instructions for students in some projects has been introduced. One of the most important elements of any approach to minimising problems with cheating and freeloading is the clear and unambiguous communication of the rules and expectations of teamwork. For example, in the cornerstone project in first year design, five PowerPoint slides in the project handout are devoted to the team process and its rules, which are discussed in detail in the introductory lecture on the project. Project tutors are also instructed to spend time on the team building process, and monitor their classes for any indications of irregularities or inequalities in team work.

A confidential peer review process has been applied and refined over a number of years. Its role is mainly as a tool to discourage students from freeloading and cheating, rather than as a 'stick' to identify and punish inappropriate behaviour. In order to get honest and meaningful answers, the peer assessment questionnaires used require each team member to prepare a summarised table with the team's work pattern during the project. On that basis the overall 'ratings' (not marks!) of each team member and of the team as a whole have to be specified. Although this is optional, the vast majority of students also make open-ended comments, which often demonstrate a high level of reflection and insight into the teamwork process, which is an important learning outcome in itself. To maintain confidentiality, students are provided with an electronic copy of the questionnaire at the start of each project, and the completed form must be electronically submitted at the time of final submission.

The efficacy of this peer review procedure is demonstrated by the very small number of genuine problems with cheating and freeloading that have had to be addressed since its introduction in its current format in 2001. In 2004, for example, there were only 2 cases in the first year design class of about 550 students where minor irregularities were discovered. These were able to be resolved without disciplinary consequences by conducting separate interviews with the affected students. This is in stark contrast to some of the comments received in student feedback in the past, where complaints about unequal work efforts of team members were not uncommon.

Team Contract

An important new tool which has further improved teamwork processes in PBL was introduced in 2003: the Team Contract. At the start of the project students receive a sheet with team contract guidelines, which cover the main issues that have proven to cause problems during teamwork. Students are asked to discuss the guidelines during their first team meeting, and define and record in writing their own rules regarding the following issues:

- Goal of the project,
- Communication within the team,
- Meeting rules and procedures,
- Resources and time management,
- Decisions,
- Establish each team member's responsibilities.

In order to stimulate students to take the team contract seriously, each team is required to submit a copy of their contract to their tutor soon after start of the project. Again, a feedback mechanism has been applied to optimise the format and application of this approach, and to gauge its effectiveness in terms of learning outcomes. As hoped, the feedback received by students has been overwhelmingly positive, as demonstrated by this typical response received in a fourth year design course in 2004:

"We had the team contract as a back up, and I was expecting to have to use it at some point to resolve a difference of opinion that could not reach a consensus. However, the whole team was sufficiently committed to the success of the project that we did not once have to refer to the team contract.

I do believe that the team contract is a useful instrument though. Although this team worked well together I have been in groups previously where a team contract would have been very valuable."

Conclusions

The strong emphasis on PBL and the consideration of the requirements of modern professional engineering practice in the School of Engineering have resulted in a cohesive and effective four-year engineering curriculum. PBL has become an important element of the undergraduate degree programme, and a common avenue for the application of concepts covered in various engineering science courses, and for other, non-engineering aspects which have become more and more important for the engineering profession. Common challenges and problems associated with PBL, such as freeloading, project organisation and monitoring, and assessment, have been identified over the years of its application. These factors have been addressed through a process of continuing improvement, and a range of 'best practice' solutions have been applied to optimise the benefits from PBL for engineering students.

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