The use of Project Based Learning in Engineering Fundamentals

Trudy Harris; Aidan Bigham
Waikato Institute of Technology
Trudy.Harris@wintec.ac.nz

CONTEXT

This paper will explore the initial use of Project-Based Learning (PBL) in a first year Diploma module in Engineering Fundamentals. The module consists of a number of key concepts that align with later modules within the Diploma, for example, Stress and Strain; Kinematics; and Heat and Temperature. The module runs the length of the semester and uses student centred activities to explore these key concepts. The students in this compulsory module are from the Mechanical, Civil and Electrical disciplines, they range in age and in their prior knowledge and experience. PBL was incorporated into the module to allow students to explore and further underpin some of these fundamental concepts, and to provide them with the practical skills needed as engineers working in the real world.

Thomas (2000) stressed that PBL had to be realistic, student driven and central to the curriculum. In this application of PBL the tutors provided the students with a project which had to be completed by the end of the semester. The project scenario required that the work be undertaken by consultancy groups made up of 6 or more students (decided by the tutors). The scenario was such that it would require the groups to consist of engineers from the three disciplines. The students had to identify the major outputs, allocate roles and tasks and manage their time to ensure that they successfully accomplished the project.

PURPOSE OR GOAL

The purpose of this study was to explore whether the initial use of PBL within the module provided students with further opportunities to support their learning and to promote engagement with the fundamental concepts of engineering.

APPROACH

A process of data gathering was structured around the running of ‘Project Sessions’. These sessions ran every two weeks over a semester of fifteen teaching weeks. Data was collected, using in-class surveys, at the start of the semester, and at various times during the semester to try and determine whether there was a shift in thinking from the start of the project to the end. This data was supplemented by informal feedback, student assessment and end of semester marks.

ACTUAL OR ANTICIPATED OUTCOMES

In answer to the question ‘*Do you think including the project in this module will improve your learning?’* 87% of the respondents to the initial questionnaire responded positively. Typical student comments include “*Yes I enjoy the hands on learning as well as in class. It reinforces my bookwork and helps me remember*” and “*It helps us improve our teamwork skills, also real practical projects for us to have our skills in our specific fields”.*

Some of the more negative aspects of the students’ comments tend to come from those who are not happy with group work, for example “*I think project work will help me to learn but I am unsure about the group aspect…If it is a bad group there is a chance it could become harder for someone who is not confident already”.*

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

The data so far shows that the inclusion of PBL into the module has been useful for the students’ learning. There is also evidence to suggest that engagement with key topics has also improved.

KEYWORDS

Project Based Learning, Student Centred Learning

INTRODUCTION

Background

Getting to grips with fundamental concepts of engineering such as Stress, Strain, Forces, Electricity and Kinematics can be difficult for many first year students. For some, these concepts can appear alien and counter-intuitive. To address the difficulties faced by a students' understanding of these fundamental concepts, tutors need to have a wide range of teaching strategies and approaches. One such strategy is Project Based Learning (PBL).

Project Based Learning provides the students with a context in which to experience, explore and interact with a particular area of knowledge. The students construct the knowledge that they need to know, and at a pace suitable to their particular learning needs. Using a qualitative approach Moti et al. (2003) showed that introducing PBL into a Mechanical Engineering course provided a number of positive outcomes including increasing student motivation to learn, development of intuitive thinking and problem solving. However, while the benefits of PBL are not in doubt (see the work of Thomas (2000) for an overview of research in the area), it can be difficult to incorporate PBL into a course. This paper will look at the incorporation of Project Based Learning in a first year Engineering Fundamentals course for the first time, and some of the issues identified by the students, at the end of the project.

The Course

This paper looks at the initial implementation of Project Based Learning (PBL) into an Engineering Fundamentals course at Waikato Institute of Technology (Wintec). The course runs in the first semester of the New Zealand Diploma of Engineering (NZDE) and acts as an introduction to the later courses in the NZDE. It covers a range of different concepts such as Stress & Strain, Forces, Electricity and Kinematics. The cohort of students include the Mechanical, Civil and Electrical Engineering disciplines and have a wide range of ethnicities, ages and experience. There were 54 students enrolled in this class.

Previously this paper was taught along traditional lines with classroom based theory classes supported by workbooks and laboratory sessions. Assessments included lab reports, an assignment, 2 internally set tests and a national final exam. However, while student pass rates were consistent nationally, feedback from many students and from staff teaching the more advanced papers, highlighted that this approach did not allow the students to grasp some of the practicalities and real life applications of the main concepts. This suggested that a change in the teaching and students' learning was needed for this paper.

External factors

While internal feedback highlighted that some modifications were needed within the Engineering Fundamentals course, externally within New Zealand there has been an increasing call from employers for graduates that are effective communicators and team players. The development of these skills has been seen by some potential employers as being almost as important as engineering skills and knowledge. The need for graduates who were work ready and had the necessary 'soft skills' was becoming increasingly important. Indeed as far back as 2005 Dym et al. showed that this was a factor in the development of PBL in engineering courses and not necessarily confined to New Zealand. With the Tertiary Education Commission focus on STEM provision and the NZ Government focus on increasing Engineering Graduates (Joyce, S. 2014) the use of teaching strategies that develop team working skills, communication and engineering process were becoming increasingly important.

In 2014, the Waikato Institute of Technology opened its new Engineering and Trades facility at the Rotokauri Campus in Hamilton. This facility was designed to facilitate the use of student centred-learning. Therefore this approach was adopted across the whole of the Centre for Engineering and Industrial Design including the Engineering Fundamentals course. Using this approach the students were no longer being passive observers in the classroom they would have to take ownership of their learning and drive it forward. Within Engineering Fundamentals this meant that the traditional approach would be replaced with classes composed of 'snippets' of theory reinforced with activities, such as a student designed tensile tests, or calculations and measurements. As well as these classes there were also project sessions. Running once every fortnight these sessions allowed the students to engage in PBL.

The Project

In his review of the literature on PBL Thomas (2000) stressed that for the students to benefit from PBL the context provided for the project should be realistic and related directly to the curriculum. The aim of the project for Engineering Fundamentals was for student groups to design and build structures that would link with their disciplines but also link with specific areas in the curriculum. At the same time it was important to develop team working, communication and problem solving skills. To achieve all these aims the tutors grouped the students into multi-disciplinary 'Consultancy Groups'. Generally these groups were teams of six students with a pair from each discipline. Students were able to choose which areas of the project they worked on, with some choosing their specific discipline areas, and others choosing to work on other areas.

For realism, we chose as a client, a military engineer with the New Zealand Defence Force (NZDF) who needed a consultancy group to develop a transportation system to move toxic waste between two embankments in a military installation. The groups had to come up with designs for a bridge, a vehicle to transport the waste and a security system to allow access to/from the bridge.

At the outset the students were made aware of specific milestones that they had to achieve, and they had to show how they were going to manage time and allocate tasks over the semester. Assessments were arranged around the engineering design process with the first assessment covering concept generation and project planning, and a final assessment which included a report (submitted as part of the assessment for another course. For more information on this see Bigham & Harris (2014): submitted for this conference) and presentation which included detailed designs of the chosen concept. There was also a final test of their designs, which required all three artefacts to work together.

PURPOSE

The purpose of this piece of research was twofold, to determine: 1. Whether the PBL activity within this course allowed the students to construct their own knowledge of key engineering concepts, and ergo, whether the students' understanding of key engineering concepts had improved; and 2. Was the design of the project suitable for making the linkages between theory and practice, and for developing team and problem solving skills? These questions were then further broken down into a number of sub-questions for investigation:

- Did the students take ownership of their learning?
- Did the tasks allow the students to make connections/linkages between PBL and theory?
- Did the students develop team working and problem solving skills?
- Did the students' marks and overall pass rate improve?

This following sections will provide an overview of the findings of the research and provide the students' thoughts on the use of PBL in their learning.

METHODOLOGY

To determine the usefulness of the PBL activity in developing the students' learning it was necessary to ask the students' for their views and perceptions of PBL, and also whether they believed the project was helping them to learn. To do this, data was collated from a number of different sources. These included:

1. Qualitative data was collected from student surveys conducted at the beginning and middle of the project to assess any changes in class perceptions
2. Qualitative data was also taken from student reflections on the project which were handed in at the end of the semester.
3. Quantitative comparison of student marks from the first year of introduction of the project with earlier years.

RESULTS

Ownership of learning

There have been a number of comments that show that the students are engaging in the development of their project and are extremely committed to the process. The quote below from the mid-semester survey shows that the project is producing a high participation in class:

> *"It shows in principal how we apply what we are learning in class. It is good in regards to participation & also keeps us in practice with writing reports."*

While the quote below shows how motivation developed from the pursuit of knowledge in an unfamiliar field…

> *"Well for me, I actually didn't know anything about electrical stuff until we got to start on our project. While researching for designs I also learned things about it. Thinking about how would our security will work gave me motivation to study some few things coz I was keen to see how it would actually work."*

The number of comments concerning Ownership of Learning is difficult to pin down with this data as this area was not specifically targeted in the survey questions, and has rather developed over the duration of the project.

Linkages to theory

In the student survey at the beginning of the course the students were asked for their perceptions of the project and its inclusion in the course. In response to the question *Do you think including this project in this course will improve your learning?* 93% of the students responded positively which such comments as …

> *"It will enable me to get to see the practical side of theory"*

and…

> *"Because what we've been taught is being put in a practical manner."*

In the second survey this process was further reinforced by some of the student's comments, and showed that they were making the linkages with theory. For example:

> *"The project we have been doing for the past few weeks is really helpful to understand the basics of fundamentals while doing the project we have come across with the factors like*

stress and strain, strength, the electrical concepts of switches and sensors and also the concept of bridge designs which are completely linked with fundamentals."

However, the percentage of students who responded positively about the linkages to theory had dropped to 62%, with a number of students who thought that the project did not reinforce their learning…

"Because we didn't talk about the key engineering concepts when we were building it."

and …

"Project needed to be supported by calculations. Applying class learning to practical applications. Maybe have the same criteria but the bridge has to break at a certain load."

Indeed, the end of project reflections also had a number of comment concerning the linkages to theory, which clearly outlined that there were deficiencies in how those linkages operated. For example:

"… I would like to see it [the project] tied more closely into the concepts taught during lectures. Specifically getting more in depth into how the structure of the bridge deals with the forces placed on it, where those forces go through the bridge, and how the mass of the truck affects the bridge as it moves across."

Team working and problem solving

A number of comments from the initial survey show that students appreciate the role of team working and problem solving in the engineering environment. The following comments from the survey reflects this. For example:

"Because I believe I learn better while working in groups."

"Having a hands on practical experience with engineering. Solving real problems gets the brain working in a more practical aspect which can reflect to a real life work situation."

However not every student was sure that group work would be that useful:

"I think project work will help me to learn but I am unsure about the group aspect. If it is a good group to bounce ideas off it will help. If it is a bad group there is a chance it could become harder for someone who is not confident already."

Unfortunately for some, this doubt became a reality. For example the quote below comes from an end of project reflection, and it is evident from the tone of the passage that there was a deep sense of frustration around aspects of group work:

"The major problem XXXX faced was the effort team members put in to the assignment. In our first class meeting each member gave contact emails and agreed to "out of class" meetings. The weekend after the individual assignment each team member was to email the others their findings to be looked at as a collective but only three people managed to do this, the first out of class meeting was attended by the same three people. This would become a common theme throughout this project but unlike in real business there was no incentive to commit to the team."

Marks and pass rates

Table 1 below outlines the average marks for the various assessments within this course for the last three years. The table provides two years of data which covers the course while taught using the traditional mode of teaching and one (2014) with the inclusion of student centres-learning and PBL.

Table 1: Average marks for various components of assessment for Engineering Fundamentals

	2012	2013	2014
Project	57.6%	62.9%	63.5%
Tests	64.5%	50.1%	52.0%
Exam marks	50.1%	49.6%	52.0%
Overall	**54.7%**	**53.7%**	**58.4%**

*Please note that the project prior to 2014 comprised 2 lab reports and an assignment

The second table (Table 2. below) shows the Pass rates for the various assessments that are used in Engineering Fundamentals.

Table 2: Pass rates for various components of assessment for Engineering Fundamentals

	2012	2013	2014
Project*	68%	85.2%	100%
Tests	82%	64.9%	74%
Exam marks	68.2%	74.5%	74%
Overall	**62.3%**	**72.4%**	**72%**

*Please note that the project prior to 2014 comprised 2 lab reports and an assignment

The following section will discuss the findings of the research at this stage.

DISCUSSION

From there results of the research it can be seen that the use of PBL within the engineering Fundamentals course has proved to be a very useful tool in engaging the students with challenging fundamental engineering concepts. However, while there is good evidence that the use of PBL has been beneficial to the students' learning what is also evident is that there are particular issues that need to be addressed when incorporating PBL into a course. The following section will discuss some of these benefits and issues.

As with Moti et al's work (2003) it can be seen from the survey comments that some students, when faced with a lack of understanding in certain areas, actively sought out solutions and continually strived for understanding. So by taking ownership of their learning and actively engaging with difficult content is the kernel for the development of sound problem solving skills. Unfortunately, the ability to study this area further is limited because of the small number of qualitative responses gathered concerning this question. The design of the survey instrument did not target this particular area, so the data obtained is through good fortune rather than design. However, that aside this feedback has shown that PBL, as used in this context, has shown great promise in terms of developing both motivation and ownership of learning.

Some further benefits that were evident initially were the linkages from the project work through to the theory being delivered in the classroom. Most of the students from the initial survey were clear that the project would reinforce their learning because they were being given the chance to put theory into practice, but what is quite clear is that as time and the project progressed, this view changed. In the mid-term survey 31% of students now believed that that the project was not adequately linked to theory. It is clear from their feedback via the survey and the final reflection that the students were able to design their bridges, cars and security systems without recourse to the theory, simply through 'over-design' and the materials provided.

The lack of links between theory and practise is also noticeable from the data on the average marks and pass rates. Table 1, clearly shows that the average marks have increased for the project compared with previous years, but this could easily be caused by the ease with which the students were able to succeed at the project. This suggestion could also be supported by the 100% pass rate for the project shown in Table 2. However, this suggestion should be tempered by the fact that the average exam mark has increased over that last two years, which could indicate a greater understanding of the material Through the use of PBL and the general move to student centred-learning from the previous traditional form.

So while the project was realistic and related to the curriculum (Thomas, 2000), it is necessary to develop a context in which the students can fail to achieve a design. This could be achieved through limiting the materials used in the construction, or through using loading and weight limits on bridges for example. Therefore the students have to use calculation to determine whether a particular design will work before committing to construction.

One issue that was difficult through the duration of the project was that of team working. Even though team working is essential for the development of work ready graduates this concept always proves to be difficult for some. While most teams functioned adequately throughout the duration of the project there were definitely some that did not, as evidenced in the comments. Those teams could clearly be identified because of their mix of age and experience ranges, so for those teams which included students with industry experience mixed with those of school leaver age, and different nationalities there were definite problems. This was also exacerbated by the fact that many of the marks were 'group' marks. Indeed, many of the reflections at the end of the project included comments on communication and the lack of motivation and work by some of the team members. An appropriate strategy for team building would be useful at the next iteration of the PBL activity.

CONCLUSIONS

What is clearly evident from this piece of work is that the incorporation of PBL into a course is not as straightforward as it would first appear. Due consideration needs to be given to the choice of activity, and the particular concepts that need to be supported with the PBL activity.

The findings indicate that even a most basic project will develop motivation in students, but careful thought has to be given to ensuring that the project has a mechanism for the students to link their practical work with that of theory – there has to be a mechanism for the students to fail without the appropriate calculations and considerations. Reducing materials, and including weight limits for bridges and vehicles would be beneficial. However there does appear to be some evidence to suggest that the exam results have improved, with the average mark having increased and the pass rate remaining constant. Further work in this area will be needed to prove or disprove this.

As with all project work the use of team working can be problematic, especially with a mix of ages and experiences. A session on team building would be beneficial for the next iteration of the PBL activity.

CHANGES

The student feedback from the first encounter with PBL has prompted a revision of the activity within the Engineering Fundamentals course. What follows are a few changes that are currently being made to the running of the activity:

- The students have been asked for some key calculations, which they have to use to explain certain principles to the client
- A budget has been given for materials so that students have to work out how much they need to fulfil their design requirements
- The teams consist of 3 students and are chosen by the students. This team of 3 is then placed in a team of 9 by the tutor. This team of 9 will cover all three engineering disciplines

RECOMMENDATIONS

There are very few pieces of research that model how to incorporate PBL into a course, so here are a few things to consider when implementing PBL:

- Make sure that the students have to work to achieve the goals set in the activity, they need to combine knowledge from practice and theory to succeed.
- The linkages between theory and practice are important – work out the best way of making those linkages. Make calculation a focus of some of the PBL activity
- Think about the constituents of the possible groups within the class. Perhaps a session with the students on team work and team building would be useful prior to starting the activity. Clearly outline the expectations around team working

REFERENCES

Bigham, A. & Harris, T. (2014). Disaster Week: A Case Study Immersing First Year Engineering Students in a Disaster Context to Measure Communication Skills. Submitted for this conference

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D. & Leifer, L. J. (2005). Engineering Design Thinking, Teaching and Learning. *The Journal of Engineering Education, 94,* 103-120.

Joyce, S. (2014) *Campaign to boost engineering study at polytechs*. Retrieved August 13, 2014, from http://beehive.govt.nz/release/campaign-boost-engineering-study-polytechs.

Moti, F., Lavy, I. and Elata, D. (2003). Implementing the Project-Based Learning Approach in an Academic Engineering Course. *The International Journal of Technology and Design Education, 13,* 273-288.

Thomas, J. W. (2000). A review of research on project-based learning. Report prepared for The Autodesk Foundation. Retrieved August 21, 2014 from http://w.newtechnetwork.org/sites/default/files/news/pbl_research2.pdf

COPYRIGHT STATEMENT