Large Scale Vertically Integrated PBL

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Introduction

Project based learning (PBL) have become increasingly popular in engineering education and in many cases is more effective for the modern engineering education. (Bell, 2010; Capraro, Capraro and Morgan, 2013; Prince, 2004; Thomas, 2000; Mills and Treagust, 2003) PBL has been shown to be applicable for both small projects with a narrow developmental focus and large multidisciplinary challenges involving experts from different specialisations and fields (Engineering, marketing, artists etc.) to simultaneously achieve multiple educational objectives. PBL has been shown to be effective due to its close resemblance to true engineering, where the nature of the work has varying design parameters as well as a high dependency on professional and transferable skills. These skills can only be effectively developed if emulated using a project-based learning teaching activity. (Edström and Kolmos, 2014; Frank, Lavy, and Elata, 2003) The execution of PBL, however, has its challenges, as it tends to be resource intensive in both teaching staff and consumables. Furthermore, the students are required to be introduced to this style of learning and teaching as it is significantly different to the conventional education system to which they have been accustomed. Conventional education systems employ tutorials and classes where pre-set, close-ended problems are used during class delivery. Within a full scale PBL learning and teaching activity the reverse is true as it focusses on open-ended activities and questions. (Frank, Lavy, and Elata, 2003; Zhou, C., Kolmos, A., & Nielsen, 2012)

In addition to PBL as learning teaching activity, there are evidences showing that learning can be accelerated when students are placed in teams with heterogeneous ability levels. (Johnson, Johnson, and Smith,1998; Millis and Cottell,1997; Springer, Stanne and Donovan, 1999) A student can model off another student who has developed a skill and elevate their expectation and performance to match with the other student. Conversely, students who have developed transferrable skills will be able to teach and mentor other students who have yet to acquire the skill competency. Through this skill transfer development both student parties will be able to improve their own knowledge in the area. We have, therefore, combined these two learning and teaching elements into a single combined 2nd/3rd year engineering unit designed for the development of transferable skills and application of technical engineering skills via a vertically integrated PBL. The paper will discuss the learning process and effects we have observed in implementing this innovative PBL teaching approach to deliver authentic learning experiences for our engineering students.

Approach/ Methodology

The teaching implementation reported herein is a combined 2nd and 3rd year engineering unit in the Bachelor of Engineering (with honours) at Macquarie University, the unit codes are ENGG200 and ENGG300, respectively. These two offered units are a part of the SPINE curriculum that is designed for the deliberate training and development of both transferable skills and employability skills. From here onwards, the units will be referred to as the vertically integrated project-based learning (vPBL) activity. This vPBL activity has a combined total of 380 students split between the two year levels. The activity involves the use of a single engineering project for students to contextualise their technical training and emphasise transferable skills development. To add an additional layer of realism, the engineering project was designed around a contemporary topic at the time of running. In 2018, this was an automatic robotic aisle picker, based around the online retailer Amazon setting up base in Australia. Students were tasked with the design and implementation of a minimum viable robot that can retrieve food cans off a shelf in our simulated supermarket within the active learning space.

There were four AndyMark *TileRunner* robotic bases used for each of the classes scheduled. Within each of the class there were three specific domains: *Comms*, *Motions* and *Structs*. Each domain can be directly mapped to the different engineering programs on offer at the School. Furthermore, each of these domains relates directly to an aspect of the robot platform. For the *Comms* group, their main concern was the telecommunication and software development of the project, whereas *Motions* dealt with power, actuators and sensors and finally *Structs* dealt with the physical structure design and mechanical manufacturing of the project. Within each of these domains there consists 4–7 groups each with 3–7 student members from 2nd and 3rd year. Table 1 summarises the class groupings and their corresponding responsibilities.

Table 1: Summary of student group numbers in different tutorial classes (T1, T2 etc.) 2018 offering for the vPBL implementation

	Classes			
Domains *(tasks)*:	**T1**	**T2**	**T3**	**T4**
Comms *(Software and telecoms)*	5	6	4	5
Motions *(Actuators and sensors)*	7	4	5	5
Structs *(Mechanical design and manufacturing)*	7	7	6	5

Each group consists of 3–7 students with a mix of 2nd and 3rd year students

The mixture of the student groups from the different years is important in providing the heterogeneous co-learning environment. Similarly, the three distinctive domains and segregation of job tasks in the overall project, enables students to comprehend the interdisciplinary nature of a real engineering project. As the different cohorts have different learning outcomes (Table 2), the students have a different subset of assessment task being evaluated on the overall project. (Table 3)

Table 2: Summary table of different learning outcomes for the two cohort years

LO	**ENGG200** (2nd years) (Students will be able to…)	**ENGG300** (3rd years) (Students will be able to…)
1	apply structured problem solving and design processes at an intermediate level.	apply specific problem-solving approaches including problem decomposition, system-level modelling, model refinement, manufacturing costing, and background research.
2	measure engineering activities as financial risk and reward.	develop and apply the appropriate activities to budget the financial risk and gain for any engineering endeavours.
3	incorporate social responsibility and sustainability into their designs.	demonstrate understanding and implementation of standards.
4	develop their understanding of interdisciplinary approaches to projects	demonstrate understanding and implementation of Engineering projects.
5	will demonstrate competency in written and oral communication of technical concepts in engineering.	demonstrate a working knowledge of engineering documents and their preparation.
6	will demonstrate self-directed, rapid learning.	assess and incorporate feedback and new technologies as part of continuous improvement and learning.

Table 3: Summary table of graded assessment for the Unit

Graded assessment tasks	ENGG200 (2nd years)	ENGG300 (3rd years)
A1. Weekly Submission (individual)	45%	-
A2. Drafting of Requirement Document (*)	-	10%
A3. Progress Presentation	10%	-
A4. Group Milestones (organisational activities)	25%	-
A5. Testing Document (*)	-	18%
A6. Acceptance Document (*)	-	12%
A7. Final Product	20%	-
A8. Final Report Submission, reflection (*) & Final product	-	50%
A9. Group Milestones (organisational activities)	25%	-
A10. Management Reflective Journaling	-	10%
TOTAL	**100%**	**100%**
(*) Group submission, but individualised marks were calculated with peer evaluations		

The graded submissions were designed to encourage 2nd year students to contribute towards the milestones that were important for the for the 3rd year students. This ensures 3rd year students are likewise incentivised to assist and facilitate the 2nd year students to perform in achieving their tasks. Some tasks, such as the A1 Individualised Weekly Submission, only concerns the 2nd year students so it is also important for them to perform individually on a consistent basis.

A Gantt chart of the different stages of the project is presented in Figure 1. Collectively the student groups formulate their ideas in Weeks 1–4, which includes problem decomposition, problem definition, brainstorming, ideation and idea variance. In Week 4, the 2nd year students present their ideas to the class and collectively agree upon a single solution. During this phase students often cross pollenate their initial conceptual design such as including an extra design feature from one team onto the main solution of another. By the end of Week 4, the students have finalised the specification for their subsystem of the robot. For example, one group would agree to be responsible for the chassis of the robot body and another responsible for sensors for line recognition on the robot. From Week 5 onwards, students self-organise to arrange their internal talents to aim to implement their minimum viable product.

Through the process students are required to plan their full project using the project planning tool *Jira* and are also required to document the project using the document management system *Confluence*. These software tools were chosen as they are typically used in industry and are generally regarded as industry standard solutions. Students need to periodically export the documentation such as for assignments A5 (Testing document), A6 (Acceptance document) and A8 (Final report). These exports are from Confluence for group submission into the university learning management system. The “external” submission was regarded as “update for clients”. Around Weeks 8–9, student groups begin to integrate their subsystem onto the final robot base. In Week 13, students presented their final product at our inaugural School wide PBL demonstration event. The Faculty Executive Dean and the wider community were invited to participate at the event.

Students feedback survey was conducted at the end of the unit and feedback were given on future improvement of the course; however, the bulk of this learning will be presented in a future paper when the 2nd implementation of unit will be ran along with any empirical data collected.

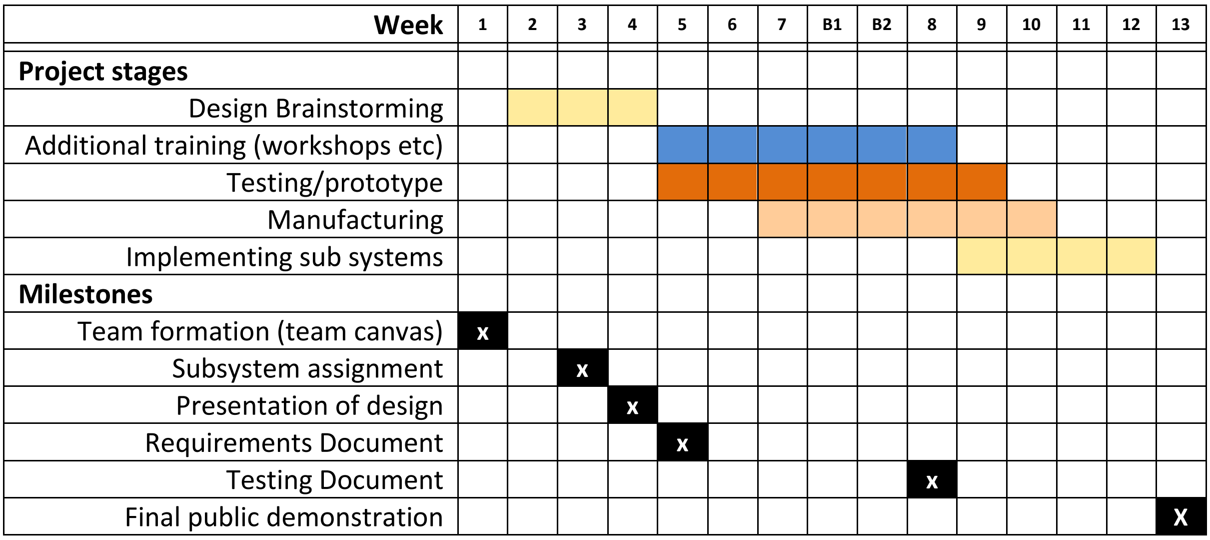

Figure 1: Scheduled of events for the project in the teaching implementation

Result and Discussion

The overall project was well received by a majority of students and teaching staff. Many of the noteworthy points were around the emulation of a real engineering project, the scaffolded learning activities and the large scaled integration of interdisciplinary engineering domains that are typically involved in a real-world engineering project. The complexity of the teaching implementation comes from the organisation of students into groups and attempts to decouple the issues with subsystems that are not performing from the integrated project. As with many large scaled systems engineering projects, some of the biggest challenges are communication between subsystems, bottle necks, and challenges involving the coupling of subsystems (e.g. interfaces, standards, delivery time etc.). In order to preserve the two key principles of this project, which are: students' agency and real-world engineering, the organisation of the project was less prescriptive on the engineering solution but rather on the processes and milestone that are involved.

Student Agency

It is viewed that student agency behind their choices in the project delivery is a key mechanism for engagement. (Beames and Brown, 2016; Martin, 2004) The initial team formation activity where students are empowered to evaluate each member's talents promotes self-evaluation and agency behind the organisation of the team. Subsequently the running of the project also allowed students to advocate their own ideas and solution for the engineering project. The agency behind their ideas is preserved to some extend when students had to further cross pollinate their ideas and derive new design variances in Week 4 during the class presentations. The organisation of the discussions was facilitated by domain experts; these are academics who have an in-depth knowledge on the complexity and viability of the ideas being presented and whether they could be achieved within the timeframe of the unit. In cases where the student's solutions were not viable, there were learning opportunities for the students in which domain experts expressed their concern and allowed students to learn the concept of design constraints that were restricting their ideas from moving forward. The project also presented a great learning and teaching platform to introduce design thinking for students. This allowed the students to develop a systematic and globally creative problem-solving skill. Furthermore, it was obvious from the student feedback conducted that most students appreciated the agency behind their choices and implementation of their design. With comments such as:

"I personally enjoyed this course very much. in this course, I was able to participate in a project of making a robot which was pretty much new to me. I got to know new faces and learnt new things."

Scaffolded Approach

The overall schedule of the project in these units was designed to maximise iterative exposure to key engineering concepts. (Gomoll, et al., 2018) Concepts that includes design constraints, interface, functional requirements, and transformative skills including communication skills, documentation, teamwork and accountability. The transformative skills development requires multiple exposure, repetition and practice before the skill is of a competency that may be regarded as learnt. Students do not simply develop teamwork skills in one or two sessions of teamwork. The development of these skills must be scaffolded and iterative with purposeful reflection between each key exposure. Therefore, in these units, we have also implemented a few key scaffolding mechanisms designed to encourage students to appreciate and develop these key skills.

The first scaffolded skill is reflective practice. The students are required to submit reflective documents at two key points in the unit; at Week 7 and at Week 13. These activities are design to focus and draw student's attention to the positive or negative experience they have had when working in their groups and in general to reflect on any of the transformative skills. A list of potential topics is given for students to choose from. This was a modified list from the consolidated topics listed in the CDIO 2.0. syllabus. (Crawley, et al., 2011) Within this list there are many topics that may be regarded as threshold concepts, such as tolerance and uncertainties to measurements. These concepts at a high level are hard to understand unless they are well contextualised within a setting. Settings such as these projects enables students to directly comment on their experience and relate to these topics.

Another scaffolded teaching implementation used was the repeated feedback/grading of the same engineering documentation. Students were tasked to define the engineering problem through submitting a requirements document. They had to submit this document as a living document, as subsequent submissions required, in turn; a testing section, then a maintenance section and finally to include any testing results. The submission of the document was in tranches, and after each submission students received feedback from the teaching staff on the document and were required to make any changes required from the feedback as well as adding the next section extension for the subsequent submission. Students were also asked to include the previous submission in the appendix of the document to illustrate the iterative changes made to the document. This closing of the feedback cycle is rarely implemented for most written reports at university level. This is due to the intensive workload that is required to repeatedly assess the work. However, it is also this purposeful proactive and iterative feedback cycle that enables students to learn from their mistakes and improve their written communication. There have been reports of an overall decline in quality of written communication in graduates across all disciplines. (Barrass, R. (2005); Dansieh, 2011; Williams and Takaku, 2011) We are anticipating that the use of such iterative feedback in 2nd and 3rd year may improve the overall development of written communication skills needed for the rest of the curriculum.

Industry Standard Software

This unit is designed to emulate as closely as possible a real working engineering environment that includes realistic engineering problems, solution processes and interaction. To facilitate this emulation, we have employed the Atlassian Jira and Confluence products as project management and documentation software, respectively. These two products have become an industry standard across multiple industry sectors. Students are required to employ an agile project management approach to develop their minimum viable product within the given time of the semester. Students use Kanban boards and agile project management approaches via JIRA. Students are also required to document and perform all collaborative documentation via the Confluence software. We have purposefully discouraged students from using Facebook and other social media platforms to organise themselves or perform any tasks that are related to this project. These platforms are not designed for professional functions and hence does not facilitate the narrative of a “professionally emulated project”. Instead, student groups have been encouraged to use email, or instant message through Slack, as is becoming more common within professional organisations. The mode in which students communicate outside the classroom environment will extend the narrative to ensure that a professional demeanour should be maintained.

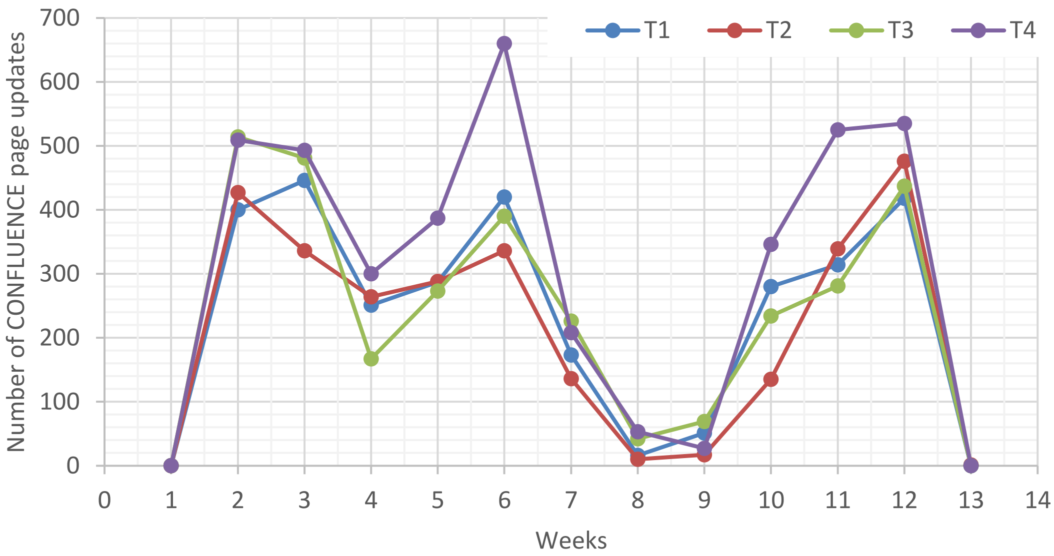

Figure 2: Students activities of documentation and page updates across the semester for the four classes. Semester break was labelled Weeks 8 and 9 in the graph.

Furthermore, the use of Jira and Confluence enables the tracking of student engagement on this project outside class, as all interactions on these products have time stamps and user information. Using these meta-information sources the student’s commitment to the project and consistency of work output is easily trackable. Through the use of analytics, such as evaluation of student’s page updates on Confluence, it can be extrapolated that students are indeed working on their submission and documentation outside of class and is fairly consistent, with the exception of a minimal engagement level during the semester breaks after Week 7. (Figure 2) The analytics of student‘s engagement is highly correlated to the effectiveness of the student teams and hence their final project solution. These findings will be reported in future studies.

Study Artefacts

As a part of the unit, students are required to submit reflective documents on their personal learning on transferable skills developed. These written reflective pieced have been designed to consist of a defined format that is highly relatable to typical interview questions at a job interview. The use of the two models: Situation, Task, Action and Result (STAR) and the Describe, Examine and Articulate Learning (DEAL) were used to scaffold students into recounting the events they experienced and extract their learning. We emphasised the use of these techniques as it would prepare students for future job interview where student’s experience with such transferable skills is highly relevant. As this unit and other SPINE units within the series has been designed to explicitly develop transferable and employability skill for our engineering students, each student’s study artefacts are an integral part of the design.

Future Work

The benefit of this vPBL approach to contextualise engineering education is not fully realised until the subsequent offering of this unit when the 2nd year students become the 3rd year students. The iterative learning cycle again occurs when students are exposed to the learning environment for multiple times. It is envisaged that the reflective practices that will be submitted will be more in-depth as students have a previous experience to benchmark against. Students will also be participating in a different engineering challenge and will be working with different students than in their previous offering. This change in project and cohort will further their development in team working and communication skills. The use of a different engineering challenge will also emphasise the importance of the invariance in the engineering approach, that is, the process involved. Through a number of students' feedback there will also be changes to the mark allocation and grading categories that are involved in the project. Futher and constant improvements will be made to the project and the running of the vPBL to ensure authentic learning opportunities are achieved.

Future studies will include analytics as a formative feedback tool for students to monitor their performance. Ethics application are also planned for collecting empirical data around effects of co-learning environment and its efficiency in a PBL environment.

Conclusion

The vPBL teaching implementation discussed herein is a part of the SPINE units within the Bachelor of Engineering Program at Macquarie University. The units are designed to contextualise the student's learning and enhance the application of their technical knowledge whilst simultaneously developing transferable and employability skills. The vPBL is an innovative approach to deliver a sense of real-world engineering in a learning and teaching environment. Using a mixed year (2nd and 3rd year) arrangement and contemporary engineering challenges, students are placed in an environment to be inculcated into the professional behaviour and processes involved in solving real engineering challenges. The vPBL approach employs a mixture of teaching methodologies such as scaffolded feedback cycles, reflective practices, and industry standard software and approaches. Future offerings of the vPBL will see the 2nd year students progressing to be the 3rd year students and that iterative cycle and cross-year level learning will be observed. It is envisaged that the benefit of this cross-year setup will be fully realised at that point.

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