Transforming engineering students into student engineers through multi-course project-based learning

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BACKGROUND

The undergraduate learning and professional work environments differ in many ways. One difference relates to how projects and tasks are approached and managed. Within the learning environment there is wide variability in how students approach assessment tasks and assignments. Some students start their work at the earliest opportunity and some students leave their work until as late as possible. Conversely, within the professional work environment projects are formally planned, monitored and controlled through defined project management tools and processes.

The inclusion of project management tools and processes within the undergraduate engineering curriculum is not new. Their use is an element of the Engineers Australia's Stage 1 competency standard, and activities such as the Final Year Engineering Project (FYEP) can provide the opportunity for students to demonstrate their application. However, not all FYEPs use this opportunity and other opportunities exist within degree programs.

PURPOSE

The purpose of this study was to explore the impact of, and challenges associated with, requiring students to apply formal management processes and tools to a design project undertaken in a concurrent course.

METHOD

A project based learning (PBL) exercise was developed in the third year *Engineering Management and Planning* course to introduce students to the fundamentals of project management. In preference to constructing a scenario, or providing a case study for use, students were required to formally plan and manage their own design project in a concurrent course. The plan, documented evidence of its implementation, and an individual reflection at the conclusion of the project were used for assessment. The student reflections were also used by teaching staff to assess the effectiveness of the exercise and identify areas for improvement.

RESULTS

The introduction of the PBL exercise from a teaching perspective has been beneficial overall but has also been challenging, particularly in relation to the timing of suitable design projects in concurrent courses. From a student perspective the individual reflections indicate varying levels of engagement with the exercise, resulting in varying student outcomes.

CONCLUSIONS

Project management tools and processes are used in the professional work environment to maintain standards and/or improve project outcomes. By requiring their use at the undergraduate level the difference between how students and engineers approach their work has the potential to be reduced, thereby better preparing graduates for employment.

KEYWORDS

Project management, industry practice, professional skills.

Introduction

The undergraduate learning and professional work environments differ in many ways. The differences between these environments have been recognised, as has the need to reduce the differences between the two (King, 2008; Trevelyan, 2010).

The focus of this paper relates to how projects and tasks are approached and managed differently in each environment. Within the learning environment students self-determine how they will approach their studies, and this may relate to what has worked for them previously. Some students start their work at the earliest opportunity and some students leave their work until as late as possible. Some students are focussed on achieving the highest possible grade while others are just happy to pass. Conversely, within the professional work environment engineers work within a controlled management system framework which requires the application of formal project management processes and tools on all projects, to maintain standards and improve outcomes.

This gap between how students and engineers approach projects and tasks is addressed to some extent in a Final Year Engineering Project (FYEP). FYEPs enable students to demonstrate whether they can personally conduct and manage a significant (or complex) project, and work is being undertaken to develop good practice guidelines for their assessment (Howard, Rasul & Nouwens, 2013). King (2008) reported that it was surprising that the project management of FYEPs was not necessarily required or assessed, and identified this as a potential lost opportunity to expose students to engineering practice.

It is the premise of this paper that there are opportunities within degree programs prior to the FYEP where students can be required to approach project (or design) tasks as student engineers rather than engineering students. By doing so, the development of project management and professional practice skills can be scaffolded within the program and students can be better prepared to effectively project manage their FYEP.

This paper examines the implementation of a multi-course project-based learning (PBL) exercise that requires students to formally plan and manage a third year design project. The project management task is introduced and assessed within one course, but is applied to a design project in another course using industry adapted management system processes.

Background

In 2010 a multi-course PBL exercise was introduced to support new course content relating to formal project management processes and tools. A PBL environment was chosen as it enables higher-order learning outcomes and has been demonstrated as appropriate for engineering education (Mills & Treagust, 2003; Maier, 2008; Schaller & Hadgraft, 2013). The PBL environment was also applicable as the fundamental project management processes being introduced were consistent with Bloom's higher-order learning outcomes (apply, analyse, evaluate, create) (Krathwoh, 2002). The project management processes being introduced necessitate project requirements to be *evaluated, analysed* and broken down, before a project plan can be *created* and *applied.*

The decision to use a PBL environment required selection of a suitable project for use. While a high profile project or industry case study were options, they were considered too complicated for undergraduate engineering students with minimal experience. The project needed to be at a level that the students could conceptualise, and similar in nature to what they could expect during work-integrated learning activities or upon graduation. The most applicable project was considered to be activities undertaken within their own studies. Activities and projects, undertaken as a group, within design courses are not insignificant. Similar work undertaken in industry would be required to be formally managed, or be part of a formally managed project. Therefore, the students' own studies were selected as the project.

Selecting their own studies as the project, such as a design activity, provided the opportunity for the higher-order elements of the Engineers Australia Stage 1 Competency Standard for Profession Engineers (Engineers Australia, 2011) to be demonstrated. For example, students would be able to demonstrate that they understand the fundamental principles of engineering project management (element of competency 1.6d) *and* that they can apply project management processes and tools (element of competency 2.4d) to their own work.

The inclusion of the students own work required the exercise to be undertake as a multi-course activity, as there was not an appropriate design task in the *Engineering Management and Planning* course. While this appeared challenging, it was consistent with a broader initiative within the School to develop a Management System for Engineering Education (MaSEE), which requires students to use industry adapted management system templates throughout their studies (Foley & Willis, 2013).

Course context

Engineering Management and Planning is a core third year course for students completing the Civil and Structural, Civil and Environmental, and Architectural Engineering degree programs in the School of Civil, Environmental and Mining Engineering at the University of Adelaide. The course has a cohort of approximately 200 students consisting of undergraduate students (85-90%), coursework masters students (8-10%) and exchange students (2-5%). It is the third course within the *management stream* of the programs and follows a first year introductory course and a second year construction management focussed course. The third year course includes an introduction to formal project management processes, with a focus on their application to ‘project’ work. Project work in this context relates to the activities and tasks that design engineers undertake prior to construction. In the conceiving-designing-implementing-operating (CDIO) engineering education framework the project work would be within the conceiving and designing stages.

The concurrent design courses within which the project management processes are applied are third year discipline specific courses for water, geotechnical and structural (concrete) engineering. The project management processes are applied to one of the design projects, and then the other design projects are used for comparison. The water design project is undertaken in self-selected groups of four and is the preferred project for use due to its complexity and timing. However, students have the option of using the other projects if they are not undertaking the water engineering course (~15% of students), or if they are the only student within their water group that is undertaking the third year management course. The third phase of the geotechnical design project is another option, is undertaken in groups of five to seven, and is less complex than the water project. The last option is the concrete design project. There are a small number of students who do not undertake any of these courses, and these students are discussed as a challenge later in this paper.

Project management content

The Project Management Body of Knowledge (PMBOK® Guide) (Project Management Institute, 2008) is used as the theoretical basis for the introduced project management processes, and students are provided with industry adapted templates for support, additional guidance and increased exposure to industry practice.

The PMBOK® Guide documents the collective knowledge of, and processes / techniques / tools used by, the project management community. Rather than prescribe how a project should be managed, it breaks down the life cycle of a project into five process groups (initiating; planning; executing; monitoring and controlling; and closing). It then describes the associated processes in terms of nine knowledge areas (integration, scope, time, cost, quality, human resources, communication, risk and procurement). For each knowledge area inputs are transformed into necessary outputs through available techniques and tools.

Task structure and assessment

The PBL exercise was first introduced in 2010 and has been progressively refined each year, based on the quality of student submissions and how it was implemented. The project is undertaken in groups consistent with the grouping for the applicable design task. The current (2014) structure of the assessment task consists of three parts: preparing a project plan; controlling the project in line with the project plan; and a reflection of the experience. The task structure and assessment are discussed in this section, together with an explanation of how and why they have changed over time.

Part A – Project plan

The documentation of the project plan requires the group to assess the project requirements early, break down the project into manageable tasks, allocate tasks, and schedule when tasks are to be completed. The project plan is aligned with the PMBOK® planning process group and includes all knowledge areas, except cost and procurement. Table 1 outlines how each knowledge area is addressed in the project plan.

Table 1: Project plan composition

PMBOK® knowledge area	What is covered	Output
Integration management	How do all the knowledge areas fit together?	Consolidated project plan
Scope management	What has to be done, how is it being broken down into tasks?	Brief overview plus work breakdown structure (WBS)
Time management	When do the tasks need to be completed by, what are the milestones?	Project milestones and/or Gantt chart, consistent with WBS
Cost management (2010 only)	How many hours is each person allocated for each task?	Budget breakdown (hours rather than $)
Quality management	How is quality to be controlled, how will documents be controlled, who is responsible for verification activities?	Basic quality plan (who is verifying what, and when)
Human resource management	Who is on the team, what is their role, what tasks will they be undertaking?	Organisation chart and/or task responsibility matrix, consistent with WBS
Communication management	How will the team be communicating and how often?	Modes of communication and meeting frequency
Risk management	What risks can be identified (project management and/or technical) and how are they to be controlled?	Risk assessment matrix
Procurement management	No procurement necessary	Not applicable

The format and submission deadline for the project plan has changed over time. In the first year, 2010, the plan was created by each group as a wiki within the Blackboard learning management system, with evidence of its implementation added to the wiki as the project progressed. In 2010 a cost management plan was also included and students were required to track the hours they had spent on a weekly basis (similar to a weekly timesheet). However, the wiki proved cumbersome and while tracking/controlling hours is consistent with industry practice it was too challenging for the students.

In 2011 the project plan changed to a collation of the outputs of each knowledge area and was submitted at the end of the semester, with what is now Part B and Part C. Not requiring the plans to be submitted early resulted in too many groups preparing retrospective plans and/or not starting the project plan/design project until near the end of the available time.

In 2012 and 2013 groups were required to submit their plans within 10 days of the associated design project requirements being released. This allowed at least one design session in the associated course to be attended, to clarify requirements, before finalising the project plan.

For 2014 a project plan template has been introduced, to create consistency and provide additional guidance. The project plan is submitted, as a group assignment, electronically to Blackboard within 10 days of the start of the project.

Part B – Project control

Part B requires students to provide objective evidence that their submitted Part A plan was implemented by the group. The evidence required includes minuted progress meetings, documented design verification activities and examples of how control measures identified in the risk assessment were implemented.

To complete this documentation, industry adapted templates are provided to students for use. This aspect of the task requires students to approach their project as student engineers rather than engineering students, consciously controlling and documenting where they are at against their plan through the use of templates, similar to what they can expect in industry.

This aspect of the assessment task has not changed significantly since 2011, except in relation to submission format and the level of guidance provided for the industry adapted templates. Initially students needed to collate and submit the evidence individually, but this changed to a group submission for logistical reasons.

Part C – Reflection

Part C is the final phase of the task and requires students to individually prepare a critical reflection of their experience with the task: what was effective; what was not effective; how did it compare with previous group work tasks; and how did it compare with their other third year design projects. This aspect of the project is the most interesting from a learning and teaching perspective and has not changed since 2010.

The content of the reflections vary and sometimes it is clear that the student is writing what they believe the assessor wants to hear rather than presenting an accurate reflection. However, the majority of the reflections are prepared in the spirit of the task and do demonstrate: whether the student has understood the fundamentals of project management; the level of engagement with the task; and the effectiveness of their project plan. It is these student reflections that have led to changes in the task structure each year, and have also enabled many of the observations in this paper.

Assessment

The assessment task accounts for 15% (5% for each part) of the 2014 course result. This has increased from 10% (4% plan, 2% control, 4% reflection) of the course in previous years. The increase was a result of the restructuring of other course components, and recognition that controlling the project was not trivial. An assessment rubric (extract shown in Figure 1) is available to students at the commencement of the task, and provides assessment guidance.

Project Planning and Reflection Assignment Assessment Rubric

Component	Fail (0-49)	Pass (50-64)	Credit (65-74)	Distinction (75-84)	High Distinction (85-100)
Part A: Planning – 4% (this component can be completed/complied as a group)					
Scope / WBS	No WBS or reference to assessment requirements	Reference made to assessment requirements but no WBS	Assessment requirements identified. Basic WBS provided (list or graphical)	Assessment requirements clearly outlined and linked to a WBS	Clear WBS (list or graphical) provided that is consistent with other aspects of project planning and the assessment requirements
Schedule	No schedule identified	Key milestones identified but individual tasks not identified	Milestones and individual task completion dates identified	Gantt chart developed and generally representative	Clear Gantt chart developed*
Quality**	No indication of how	Motherhood statement re	Requirements are documented	Quality of project well	Verification responsibilities clear:

Figure 1: Assessment rubric extract (2013)

The task is process oriented and assessment of all three parts occurs after Part C has been submission. Consideration has been given to assessing Part A separately and prior to Parts B and C, to enable groups to modify their plans if required. However, this has not been adopted as:

- The emphasis has been on the development and implementation of a plan, rather than its likely effectiveness (which is assessed by students in Part C).

- The submission deadline for Part A is dependent on the design project selected for use, and this could result in some groups receiving feedback on their Part A before others are required to submit it.

- Part A would need to be assessed twice. Once on the first submission, and then again when Parts B and C were being assessed, to obtain a representative view of the full project.

Assessment of the task can be time consuming as the three different parts (two group submissions, one individual submission) need to be collated into groups, to enable all students within a particular group to be assessed at the same time. This aspect was improved in 2014 with all submissions being electronic, and managed through Blackboard.

Assessing all students within a group at the same time provides interesting insight into how the groups operated and the level of engagement with the task. In some cases the individual Part C submissions demonstrate alignment between group members and genuine engagement with the task. In other cases it appears the group members have agreed on similar (but not copied) reflection content, and this reduces its effectiveness. Then, there are the groups who submit conflicting and contradictory reflections, which are a mix of honest portrayals of how the project was implemented and fabricated accounts.

Observations and challenges

Reflecting on how the task has changed over time from a teaching perspective, and on the perceived effectiveness of the task from the student perspective (as reported by the students in their Part C submissions) enables a number of observations to be made.

From a teacher's perspective, the implementation of the task has been challenging for the following reasons:

- The multi-course nature of the exercise is different for the students, and requires students to change their mindset in relation to their study workload and what work is being undertaken for each course. In some reflections students have commented that undertaking the project management activities un-necessarily added to the workload of the design task.

- Some students find it difficult to change the way they approach their work, in many instances they have achieved success using an approach that has worked for them, and don't necessarily appreciate the need to use a standardised approach.

- While the majority of the students are able to choose one of their other third year courses, there is a small percentage of the class (<5%) who do not have an appropriate project to use. In these cases it is necessary to modify the task to a retrospective exercise and this is generally not as beneficial for the student.

- The suitability of the design task does make a difference to how effective the exercise is. The design tasks needs to be sufficiently complex and include interdependent tasks so that management of the project does add value to the outcome.

Regardless of the challenges associated with the design and implementation of the task, the Part C reflections submitted each year validate the value of the exercise. The following quotes are from a 2011 reflection:

> *As other projects we have worked on have not involved any planning or structure it was expected that this project would prove to be completed in a more efficient manner. However, the extent of this improvement was far underestimated.*
>
> *In comparison to other projects the factor which made the workload most manageable was knowing what tasks to complete and in what order; no time was wasted trying to decipher subsequent parts of the brief as the group already extracted all relevant passages …. to form a work breakdown structure.*

While further research and assessment of the reflections is required to formally quantify the effectiveness of the exercise, the Part C reflections indicate that the exercise creates a net positive benefit to the learning experience when students actively and genuinely engage in the exercise. The reflections indicate:

- Reduced levels of stress, as the students know what they have to do next, and how much work is left on the project.
- Reduced re-work of calculations required due to quality assurance processes such as design verification identifying mistakes earlier than usual.
- More efficient use of time, as all team members know what everyone is expected to do.
- More productive meetings, because they have improved clarity and direction.
- Team members taking more responsibility for the completion of allocated tasks.

Conclusions

Consideration of how to better integrate professional practice into the undergraduate learning environment is expected to be a continuing challenge for engineering educators. This paper has demonstrated that the use of a multi-course PBL activity enables students to approach their work as student engineers rather than engineering students. Project management tools and processes are used throughout the professional work environment to maintain standards and/or improve project outcomes. By requiring their use at the undergraduate level, the difference between the learning and professional work environments can be reduced, with potential for positive impacts on student learning.

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