

Developing three-dimensional engineers through project-based learning

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CONTEXT

The issue addressed is the need to develop engineering students' independent learning and their understanding of the range of professional engineering activities within the context of a large introductory engineering subject in a revised academic calendar with reduced teaching weeks. Thus a project was created to re-design the subject to take a structured approach to flipped and blended content delivery. This has provided a scaffolded and supportive environment to introduce students to collaborative project-based and independent learning.

PURPOSE

The project aims to create a coherent teaching and learning narrative to develop student engineering identities within an authentic student project which gives them insights into the nature of engineering work. This is done in a subject with strong tutor support to scaffold students' learning experiences.

APPROACH

The project uses transition pedagogies to scaffold blended and flipped learning experiences, and to make explicit the need to develop students' engineering identities. Active and interactive learning opportunities enhance students' agency to become independent learners. Data have been collected from students and tutors to measure the impact of the changes in learning and teaching practices. Student data are being analysed through the lens of developing professional identity. The effectiveness of the student learning activities are being evaluated using tutor feedback and assessment results.

RESULTS

Results indicate that due to the subject redesign, students have a stronger sense of the nature of engineering work. Furthermore, teaching and learning activities that focus on project-based learning have developed students' emergent professional identity and professional capabilities. In addition, the standardisation of teaching and learning experiences across tutorial classes have led to greater consistency in content delivery and learning outcomes.

CONCLUSIONS

It is critical to introduce students to project-based learning using a structured and scaffolded approach. This foregrounds the collaborative and three-dimensional nature of engineering work and highlights the complexities of developing professional capabilities and identities. Students develop these understandings at different rates; as is evidenced in both the student and the tutor comments thus flipped learning activities can provide opportunities for students to maximise classroom and peer-to-peer learning. Even with the structured activities, not all students embrace the need to develop professional skills as part of learning to become an engineer.

Key words: engineering identity; project-based learning; flipped learning

Introduction

Background:

The expectation that university students will unproblematically develop as independent learners is often not scrutinised by university administrators and academic staff, despite extensive research in adult learning (e.g. Biggs & Tang 2007; Bock, 1999; King & Kitchener 1994; Perry 1981) which demonstrates that intellectual capacity for judgement is not fully developed until people are in their mid to late 20s. In addition, students attending Australian universities are from highly diverse backgrounds, with a wide range of prior learning experiences. To add to the mix, developments in technology “have continued to alter the modes of student participation, the structures of course delivery, and relationships between students and teachers” (Baik, Naylor & Arkoudis 2015, p.1). Gardner’s research in this area has demonstrated that “students who perform poorly in flipped learning environments typically do not demonstrate the agency and self-efficacy necessary to take responsibility for their own learning and hence have difficulty achieving the cognitive changes which are the learning outcomes in these subjects” (Gardner 2017). Thus it cannot be assumed that all students are equally ready for independent study, which is increasingly being conducted online.

In combination with the current context of higher education are the demands to renew engineering education. As Bucciarelli and colleagues pointed out at the end of the 20th century, “what is needed is a new culture of engineering education characterized by active learning, project based learning; integrated development of mathematical and scientific concepts in the context of application...[and] a faculty devoted to developing emerging professionals as mentors and coaches...” (Prados in Bucciarelli, Einstein, Terenzini, & Walser 2000). This need has only increased in the last two decades. Much energy is being directed toward producing a three-dimensional engineering graduate, as opposed to what Wulf and Fisher refer to as “the traditional stereotype of the asocial geek” (2002, p.36). The three dimensions comprise technical competence, personal/professional competence and design-oriented competence. Another way of looking at this is the combination of the technical specialist, the integrator and the change agent, where the integrator reflects the need for engineers who are boundary-crossers and the change agent emphasises the importance of engineers to provide creativity, innovation and leadership (Henley report 2006, p.60).

The constantly shifting landscape of technology and global projects has put pressure on engineering education to embrace the development of students’ professional and technical capabilities in ways that incorporate authentic learning and assessment. Project-based learning has long been regarded as one of the more effective ways to develop students’ deep and broad understanding of the field in which they are studying. There is strong evidence that problem-based and project-based learning can be successfully integrated into content-laden units of study, both deepening understanding and developing conceptual change, without loss of technical knowledge (e.g. Brodeur, Young & Blair 2002; Gomes & Barton 2005; Hadgraft & Kolmos 2007).

In addition to developing understanding, project-based learning can enhance students’ engagement with their university studies. The importance of working in groups and teams is emphasised by transition pedagogy research, which reports connections between first year students’ lack of exposure to group work and a less than satisfactory university experience. “In 2014, there was still a large proportion of students who reported never working with classmates outside of classes (26%), never working with other students on projects during class (21%), and never studying with other students (26%). Fewer than one in five students frequently studied with other students. This meant they were less satisfied with their university experience overall, and less likely to achieve high marks in the first semester” (Baik, Naylor & Arkoudis 2015, p.3).

All these complex demands thus require an approach that scaffolds blended learning, acknowledges different prior learning experiences, introduces project-based learning with authentic assessment and begins the process of developing engineering students’ professional identity as a three-dimensional engineer.

This project builds on much work that has gone before in the context of developing first year engineering students' technical and professional attributes (e.g. Kavanagh, Neil & Cokley 2011; Mann, Howard, Nouwerns & Martin 2009; Shekar 2014), and particularly studies that have used the Engineers without Borders Challenge as a way of utilising project based learning (e.g. Stappenbelt & Rowles 2009). Although there are similarities between this project and the UWA study reported on by Stappenbelt and Rowles (2009), there are also significant differences. One of the main aims of this project is to introduce students to the concept of critiquing their previous expectations of an engineering identity, and learning to construct an engineering identity that is three-dimensional. A key feature of the approach is the utilisation of learning activities which are scaffolded through pre-class activities, in-class tasks, peer learning and review, and formative assessment. As it is a core first year engineering subject, it is critical that students develop good study practices and are provided with a solid platform on which to build their independent learning. The following section describes the specific context of the research project.

Context

Engineering Communication is a large first year subject with a cohort of between 350-400 students that introduces students to the complexities of communication within engineering practice. Since its inception in the early 2000s, the subject has attempted to provide a range of tutorial based experiences aimed at developing students' professional capabilities in research, academic writing, oral presentations, evaluation of information, teamwork and peer review. Within a supported classroom environment, students are inducted into teamwork and leadership and begin to develop a sense of the nature and scope of engineering work beyond the technical skills often associated in engineering disciplines. In doing so, students' professional identity begins to form early in their academic careers.

Engineering Communication was originally designed as a series of 12 weekly modules allowing for skills development in key communication areas. In class, students were presented with activities and related materials to which they responded in an individual student workbook. Some online materials were provided to support learning; however, most students did not take advantage of the preparatory work as it was not linked purposefully to the tutorial content. Overall learning would culminate in a team literature research project and accompanying presentation based on a prescribed engineering problem. In its original form, Engineering Communication lacked both excitement and authenticity and fell short of the stated aims of the subject.

In 2012 the Engineers without Borders Challenge (EWB) was introduced to give students an authentic design project and the task of developing a solution for a genuine set of stakeholders, the aim being to introduce a broader range and deeper understanding of engineering activities. A firm partnership was formed with EWB which added a new focus and further materials to the subject. Over time the student workbook continued to grow (adding rather than deleting content) offering activities that far exceeded the weekly 3 hour timeslot. At this time there was no serious attempt to encourage pre-class preparation or independent learning as most material was presented in class. A smorgasbord approach to the delivery of content was adopted, allowing tutors to develop their own interpretation on how best to utilise the materials.

An anecdotal review of learning and teaching in Engineering Communication in 2015 revealed a high level of inconsistency across the tutorial classes for both students and tutors. Tutor meetings often revealed this disparity when discussing the range of approaches to any given topic. Although the essential framework (content topics and assessment tasks) was aligned, there appeared to be great discrepancy between what was delivered to students across the classes. In an attempt to allow tutors to develop their own content flavour relevant, the materials had over time become cumbersome and confusing. In short, the need to develop a clear and consistent subject narrative was identified.

In 2016, a move towards a new (shortened) academic calendar and the university's learning model initiative presented an opportunity to obtain support to re-design Engineering Communication. The aim was to retain the original intent, including the EWB Challenge project, while structuring class content and introducing blended learning strategies. This

required an audit of all existing content and a rationalisation of materials into 10 weekly modules; each telling its own structured “story” through a series of collaborative in-class exercises and a series of pre-class tasks. While the EWB Challenge project had been established within the subject for some time, the re-design was a significant shift to include a consistent scaffolded approach with a focus on independent learning.

Purpose

The project aims to support students through the institutional model of learning and provide guidance in blended/flipped activities so they are prepared for their engineering studies. The first stage of the project is to provide a solid platform for independent learning at university. Later stages of the project will track students throughout their engineering studies to explore how their engineering identity is developing. It is essential that students in the first year are introduced to the expectations and benefits of the approach used in the University of Technology Sydney’s (UTS) model of learning in a subject where there is strong tutor support and flipped and blended learning can be contextualised. Transition is improved as the students gain an introduction to the UTS model of learning and there is scaffolding of blended and flipped learning experiences. Because of the strong tutor support in Engineering Communication, the approach provides students with a solid foundation for independent learning in a blended learning environment which will better prepare them for transition into later year subjects. It also builds in greater “time-on-task”, and a sense of capability, which is known to be a key factor in enhancing student satisfaction and in student retention.

Engagement in an interactive, collaborative and supportive learning environment is improved as students are better prepared to participate and learn in class through a range of activities they can access on demand. The approach also significantly impacts students’ “time-on-task” as they are expected to prepare for in-class and out of class activities.

Flipped online activities for students, such as pre-class tasks that require students to complete a reading or watch an instructional Youtube clip and answer questions, have been reinforced in the tutorials. This has introduced students to blended learning in Engineering Communication so that students understand from the beginning of semester the importance of interacting with the learning management system (LMS) and with completing the pre-class tasks. Project based learning has been consolidated by teaching and learning activities that centre on the Engineers without Borders (EWB) Challenge project, which further embed the learning to the project by linking it more closely to subject content, therefore making the combination of project and content more relevant. In addition, teaching and learning activities provide feedforward and feedback on the assessment tasks; the assessment tasks have been designed to assist students to learn about project management in the context of the EWB challenge.

The move to standardised modules and the streamlined content of the student workbook attempts to provide a more consistent teaching and learning experience. This is critical in any large subject where there are several tutors and many tutorials, which can result in quite disparate teaching and learning practices and outcomes. In order to ensure that there is a shared understanding about the intended learning outcomes of the subject, workshops for tutors are held at the beginning of each semester. Tutor induction is run in conjunction with EWB to develop common understandings about expectations and the design brief; the social context for the project is set in a workshop with a discussion format.

Approaches to evaluating the subject redesign

One of the intentions of the subject redesign has been to expand engineering students’ awareness of the nature of engineering work using project-based learning in the context of the EWB challenge. Another has been to provide both students and tutors with opportunities to adapt to an innovative institutional model of learning which places emphasis on flipped and blended learning. As this is the first stage in a project to track students’ developing identity as engineers, and in order to investigate how successfully these intentions have been fulfilled, we conducted a questionnaire of students and tutors. We chose to have open-ended questions to allow student and tutor voices to be heard. The student questionnaire

was administered as an in-class activity and all responses were de-identified. There were 150 responses which is a response rate of 46.4%; the student cohort is 323 across 13 tutorial classes. The tutor questionnaire was emailed to the tutors and all responses were returned in hardcopy via a physical drop box, to maintain anonymity. Nine responses were received, which is a response rate of 100%.

Students were asked to comment on changes in their perceptions about the nature of engineering work and of professional attributes, and activities that have assisted in deepening their understanding of these concepts. This can be seen as an indicator of their professional identity development (Buckingham Shum & Crick 2012). Tutors were asked about their perceptions of changes to the subject and the extent to which they could see the development of students' professional attributes.

The anonymised student questionnaire results were compiled by a research assistant and subsequently analysed using Concordance software (Watts 2011) to quantify frequency of terms. This allowed the identification of key themes to emerge. As there were a relatively small number of tutor responses, the results were analysed by the two researchers.

Results

Analysis of student questionnaire

Defining the nature of engineering work

When students define the nature of engineering work the most prominent themes are communication, teamwork, research, and report writing. However, the responses demonstrate a range in complexity such as "I learned that to work as an engineer, I should be disciplined and have good communication and research skills" to "engineering work is not just about communication or design and implementation, it's also about the social, cultural, economic and environmental effect on society [so] engineers should be humanistic and consider lots of aspects". The range of comments reveals the different levels of effective learning that may be taking place in the subject.

50% of students who cite communication, also identify an aspect of teamwork. For example, "engineering work is very concise, communication amongst team members being the key to successful projects". Approximately 5% included activities such as critical thinking, creativity and accuracy.

Four students provide specific statements on how their ideas about the nature of engineering work have changed. Examples include "engineering is a very broad field, broader than I had in mind – a field which requires a lot of teamwork" and "I first thought that engineering requires no communication with other people, but this subject has proven otherwise".

Activities that have helped in understanding engineering work

The most commonly occurring activities listed are writing reports and research skills followed by learning presentation skills and collaborative project work. These topics relate closely to the module content offered in tutorials and students identify more than one activity in over 90% of responses. Comments include: "I have learnt writing, listening, presentation skills and others that have helped me understand engineering work" and "one activity is doing work in groups, being able to interact with other people with alike minds, giving me a taste of what it is like to interact with fellow engineers".

Two examples where students make clear associations with the assessment tasks and their increased understanding of engineering work are: "Task 2a(i) and 2b(i) have significantly impacted on my understanding of engineering work as it emulates the role a team member must perform in his group. By working alone, it taught me to treat my individual work as if it were the whole group's and failing to do so will result in letting down my group members" and "the assessment tasks have helped me greatly to understand how to research effectively on engineering content".

The pre-class tasks are identified as assisting the understanding of engineering work by "creating a scaffold of what is to be learnt in the upcoming tutorial for it to be fully constructed during the tutorial", and "reading so many articles or the text book truly help me a lot".

Pre-class tasks assisted in tutorial learning

Student responses to how the pre-class tasks assist their learning fall into four groups; those that wrote a general comment on the role of the tasks; students who state how they found the tasks useful; students who feel that the tasks are a waste of time; and students who state they do not complete the tasks.

25% of students provided specific information about how the tasks have assisted in tutorial learning, such as: "I would say it's a nice way of learning because we already know what [is] expected in class" and "it deepens my knowledge and stops time being wasted" and they "stop me from feeling lost for the period of the class".

Three students claimed the pre-class work is not useful: "not much", "quite ineffective in improving my tutorial learning" and "in my opinion they have not". The remaining group of two students did not complete the pre-class tasks and confessed: "I have not been diligent in doing these tasks" and "unfortunately I have not completed the tasks".

Introduction to professional attributes

55% of students name "communication" as the key professional attribute, which they interpret broadly. Comments such as "being able to market your ideas to an audience" and "be clear when you are speaking" are included in this category. Generally, students do not identify the faculty Graduate Attributes for the subject (Communication and Coordination; Self-management; Engineering Practice in a Global Context) even though these attributes are explicitly named in the introductory lecture and discussed throughout the semester. The responses demonstrate a trend for students to itemise attributes such as research, teamwork and writing separately from "communication". For example, 35% of responses listed writing, (including academic writing, report writing and being able to write clear concise reports) in addition to "communication".

Analysis of tutor questionnaire

Impact of pre-class tasks on tutorial teaching

Overall, there is a mixed reaction to the pre-class tasks. "Some good outcomes but most students have not adapted to the cultural shift". While the rationale behind the pre-class tasks appears to be accepted by most tutors, the responses indicate a high level of frustration that many students choose not to complete them regularly.

Tutors claim to "spend significant time screening and explaining the importance of the tasks" and it can be "difficult to run the session on the basis that the pre-class work has been completed". When tasks are not completed, tutors agree that it reduces the effectiveness of the session and students who are motivated to complete the tasks often become disappointed by those who don't. Additionally, tutors express concern that the pre-class work is seen as not challenging and not compulsory. Therefore, we are "sending a message the [tasks] are not essential to the subject". Tutors were asked to provide the proportion of students that complete the pre-class tasks most of the time. The reported completion rate was approximately 50% across thirteen tutorial groups.

Tutors who report a higher degree of success in pre-class task compliance agree that students are more engaged and the work done prior to class is helpful to the teaching and learning process. Done well, these tasks "target discussion and direct learning" while "providing background to engage and facilitate activities". There is an acknowledgement that the pre-class work "changes the way students prepare for class and that there are varying degrees of success depending on the student".

Key professional attribute introduced in teaching and learning activities

The key attributes identified by tutors represent the common and expected themes of Communication and Coordination. Some tutors expanded these areas to include personal responsibility, self- management, teamwork and working to a standard.

Ways in which professional attributes are developed

All tutors identify teamwork and collaboration as an essential element in the development of key professional attributes with "group work becoming a focal point for almost every tutorial". As students work through the project requirements "students start to think for themselves". Project-based learning in this case has "task orientated learning outcomes that are strategically employed within the subject to develop every attribute".

Tutors place importance on group work as the “element that provides significant learning” and “the need for individual and collaborative organisation in a variety of [tasks] needed to produce the group project report”. “Students, consciously or sub-consciously begin to take roles within their group which often gets disrupted as they begin to understand that they have different aspirations and goals”.

Tutors note the class based activities begin the formation of professional identity along with “understanding more about professional practice and providing a real-world context” to this learning. Comments include: students “develop a professional identity while considering their future as a professional engineer”. This becomes “evident in [student] attitudes towards the portfolio activity at the end of the subject”.

Impact of the changes to the subject

While tutors endorse the EWB Challenge and project-based learning, most raise concerns about the required pre-class tasks and how they are applied to the subject. There is a range of responses to the overall changes to the subject. Some tutors are unconvinced the changes have any impact at all. “I don’t think they have made a significant impact and I do not detect any differences in most students’ attitudes or in the quality of the reports”. A contrasting view is that: “recent changes streamline the process and make good links with the subject materials are made”. Two tutors stated they were not sure if the changes had made an impact in their classes or to their teaching.

Ongoing challenges

Tutors are agreed that motivation is a problem for some students in most classes they teach. There is a concern that “some students are not suited to this type of open-ended learning. They want clearer guidelines so they don’t have to take risks” Tutors raise the issue of cultural expectations and the reluctance of particular students to take part in group tasks. The overall sentiment is summed up with “most students are keen and easy to work with but there is always a proportion who do not want to engage”. Another ongoing challenge is ensuring compliance/completion of pre-class tasks. Tutor comments point out that some students struggle to make the cultural shift to a flipped and blended learning model. There may also be a need for cultural shift by tutors to reinforce the need for completion, and to make sure that class time is not spent on doing the pre-class tasks.

Some tutors are concerned about student standards: “there is a real and increasing challenge as the curriculum changes and student standards decrease”. Another tutor comments “students whose language is not sufficient are therefore, achieving a better outcome at the expense of those who carried the team”. A further concern noted “some students are well below university level”.

Discussion and conclusions

Overall, the student responses reflect the diversity of the cohort, the range of learning experiences, the varied levels of engagement, and the differing interpretations of the nature of engineering. This is to be expected in a large first year subject which introduces the students not only to new concepts but to new ways of learning in a new context. It is important to recognise that there are variations in expectations of what is required in university learning and that one size does not always fit all. Students also vary in the speed with which they make connections between in-class and out of class learning.

It was pleasing to see the growing awareness of the nature and complexity of engineering work and a shift away from a purely technical focus. In-class activities such as group work and collaboration reinforce this broader understanding, which starts to build a sense of professional identity. This is evidenced by both students and tutors identifying the importance of these activities in developing professional attributes.

As an introductory subject, Engineering Communication serves an important purpose by inducting engineering students into the university model of learning and commencing the development of their professional identity. However, it is crucial that later year subjects continue to develop students’ professional attributes in conjunction with the development of their technical knowledge.

The range of student and tutor response to the pre-class tasks indicates that a significant proportion of students and tutors consider that these tasks add value to their learning, and

some students could clearly articulate the benefits. For some students, the pre-class tasks did not contribute to their learning and this suggests that there is work to be done in assisting students and tutors to make the cultural shift to flipped and blended learning.

The divided opinions of the tutors regarding the changes to the subject design and delivery reflect the challenges in delivering a standardised teaching and learning experience across a large-scale subject. A consistent approach requires a shared understanding of and commitment to providing rich learning experiences.

In conclusion, these results suggest a need for a high level of collaboration between tutors to develop a clear sense of direction and purpose; students should also be part of this process and should have an opportunity to contribute to subject design. The next stage of the project will track how students develop their professional identity in the context of project-based learning as they progress through their degrees, and will explore the potential of learning analytics to map this development.

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