Demonstrating the relevance of Mathematics to first year students in Engineering courses – what are the critical elements for a successful project?

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Structured abstract

CONTEXT
First year engineering students often feel disappointed with the first year mathematics content as they expect to learn entirely about engineering design from the beginning of their studies. Moreover, mathematics is usually taught out of context, as emphasis is on learning the mathematical basics including logical thinking and reasoning skills. Since they did not sign up for a mathematics degree, students often fail to see the connections between the underlying mathematics and science units, and the skills they need to develop by graduation from an engineering degree. This lack of awareness of the relevance of mathematics content taught early in the degree may lead to students' disengagement with their mathematical studies.

PURPOSE OR GOAL
Following the completion of a pilot project earlier this year, which resulted in two high quality animated videos; this paper reports on the first steps and decisions taken to establish a project that aims to involve students in the development of resources to demonstrate to first year students the relevance of their underlying mathematics units. Emphasis is on including the student perspective, rather than rely entirely on a staff perspective.

APPROACH
The research question addressed in this paper is: "What are the critical elements for a successful project to develop student-produced resources that demonstrate the relevance of maths?" In order to answer this question, we analysed what decisions were made and how the project was designed from the start. Qualitative data includes observations from the project team, communication with faculty senior management who funded the project, as well as a report prepared by the engineering students who produced the resources.

OUTCOMES
We found that securing support early on from senior management in the form of funding and commitment to the project outcomes was fundamental to the project going ahead, and to the motivation of team members. Analysis of student comments indicates that it is critical that technical expertise is included in the production team if multi-media material is to be produced. It is vital to approach such a project in a collaborative way, i.e. both engineering and mathematics staff members must be involved as both bring different skill sets and perspectives. In addition, students believed that their perspective is important and that undergraduate engineering students should be involved in the production team.

SUMMARY
The project that we analysed for this study is a pilot to gauge if students can work collaboratively with staff in the production of resources for other students and produce a resource of high quality. From this, we conclude with the following critical elements for a successful project to motivate the relevance of mathematics:

- Support from senior management
- A multi-disciplinary team to lead the project
- Carefully selected final year engineering students and multi-media students
- Close collaboration with marketing
- A shared working space with professional multi-media equipment

It is hoped that experiences described in this paper may guide others to undertake similar projects.

KEYWORDS
Engineering Mathematics, first year, relevance, students as partners, co-creators

THE IMPORTANCE OF MATHEMATICS FOR ENGINEERING

Mathematical skills are vital for engineers, as we will demonstrate in this section. Engineers Australia has set the requirements that all graduates need to achieve by the end of their course through its Accreditation System for Professional Engineering Courses (Engineers Australia 2011). This accreditation system is an outcomes based approach, where the course learning outcomes are defined first and then these are then mapped at the unit level and finally unit assessment alignment takes place to ensure that all graduates develop all course learning outcomes by graduation.

With respect to the underlying mathematics and science skills, the Engineers Australia Accreditation Manual states that:

> *"Enabling skills and knowledge in maths, physical, life and information sciences, and in engineering fundamentals must adequately underpin the development of high-level technical capabilities, and engineering application work within the designated field of practice and selected specialisations.*
> *Graduates should have an ability to work from first principles in tackling technically challenging problems." (Engineers Australia 2011;G02, Section 3.2.4.1)*

This emphasises the importance of the underlying base skills for all engineering courses. Engineers Australia has also developed the Stage 1 Competencies, which state the competency standards required for a graduate professional engineer to practice (Engineers Australia 2012). Engineers Australia accredits courses at universities and this accreditation is a demonstration that the course has met the accreditation manual requirements and the Stage 1 Competencies. In examining the Stage 1 Competencies, the important reference to base skills is shown in section 1: Knowledge and Skill base, and is detailed in competency 1.2:

> *"1.2 Conceptual understanding of the, mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline"*
> *(Engineers Australia 2012)*

The level of attainment required for this competency is as follows:

> *"Develops and fluently applies relevant investigation analysis, interpretation, assessment, characterisation, prediction, evaluation, modelling, decision making, measurement, evaluation, knowledge management and communication tools and techniques pertinent to the engineering discipline."*
> *(Engineers Australia 2012)*

This shows that mathematics in engineering courses is a critical skill that students need to learn and be able to apply, in order to become successful engineers. It is therefore important that the relevance of mathematics is recognised and accepted by the students (Flegg, Mallet & Lupton, 2012). There are even claims that courses may need to be re-designed to improve the mathematics units in the curriculum, and in particular to demonstrate the relevance of that material to the engineering discipline (Manseur, Ieta & Manseur, 2010).

Engineering students are required to learn base skills in mathematics and science that are built on to develop engineering skills throughout their engineering degree. These base skills are needed at a higher level than are taught at high school, however many students entering engineering courses assume that they already have all the mathematics and science skills necessary to undertake an engineering course (Wilson and MacGillivray 2007).

Therefore first year engineering students often feel disappointed with the first year mathematics content as they expect to learn entirely about engineering design from the beginning of their studies. In addition, mathematics is usually taught out of context, as emphasis is on learning the mathematical basics including logical thinking and reasoning

skills with examples and exercises not bearing any obvious relationship to engineering. Since they didn't sign up for a mathematics degree, students often fail to see the connections between the underlying mathematics and science units, and the skills they need to develop by graduation from an engineering degree. This lack of awareness of the relevance of mathematics content taught early in the degree may lead to disengagement with their mathematical studies and also their engineering studies (Flegg *et al.* 2012).

Flegg *et al.* (2012) undertook a study into the experiences of first year engineering students and their perceptions of the relevance of mathematics to their engineering studies. They stated that:

> *"Mathematics departments often have responsibility for teaching mathematics to engineering students. This may lead to the situation where engineering departments have little idea of what mathematical content is presented to their students in the standard prerequisite mathematics units" (Flegg et al. 2012)*

They found that if students fail to see the relevance of mathematics, then their interest in those units would be low. One of the important results of their work was that first year students could not yet appreciate the connections between their mathematics studies and what will come later in their course: i.e. they do not appreciate what they do not know. Another conclusion from this work was that mathematics needs to be taught as a tool for dealing with real-world problems. For this to happen there needs to be close collaboration between the mathematics and engineering staff (Flegg *et al.* 2012).

Other projects

It was difficult to find literature on projects trying to motive the relevance of mathematics by involving students. However, there were a number of papers on projects undertaken to improve students' mathematics ability and its application in engineering courses. These approaches covered, for example,

- Using diagnostic tests to identify knowledge gaps and then provide material to fill those gaps (Raubenheimer, Ozturk & Duca, et al. 2010; Terrell, Terrell, & Schneide 2010)
- Delivery of extra classes or summer/pre-university studies to bring students up to the appropriate level of mathematics knowledge (Masoom and Masoom 2011)
- Delivery with first year design classes to improve students understanding of the links between mathematics and core engineering skills (Jouny and Piergiovanni 2010;Spang and Spang 2012; Lowery, Kane, Kane, Hensel, & Ganser, 2011)
- Delivery of learning support or mentoring for students (MacGillivray 2009; MacGillivray and Croft 2011)
- Setting learning in a real world context (Cunningham and Lachapelle 2012)

All of these approaches came from a staff perspective, focused on the content, and did not engage the students themselves in finding a solution to the students' perception that mathematics was not relevant to their engineering courses. Therefore, it was decided to include the student perspective, rather than rely entirely on a staff perspective, and this meant to trial a new strategy.

The project and methodology

Following discussions between the authors: a mathematician and an engineer, it was decided that a project was needed to demonstrate the relevance of mathematics to first year engineering students. The purpose of this would be for the students to engage better with mathematics and thereby improve their mathematics learning. Students would be involved in the development of resources to demonstrate to first year students the relevance of their underlying mathematics units.

Whilst analysis of the final outcome and how the videos are received by first year students is not the focus of this paper, we will give a brief summary of the project here to aid the reader in understanding the project as a whole. Two scholarships were advertised among all

engineering students, with the successful candidates coming from civil engineering and from mechanical engineering. One scholarship was available for a multi-media student, which was taken up by three multi-media students who decided to work together and share the scholarship. These five students collaborated extensively, crossing discipline boundaries with ease, as described in Loch and Lamborn (2013). The students were guided by the two authors who provided support and suggested directions when required. The students created two high quality animation videos, both demonstrating the use of mathematics, the first being in a civil engineering context with the construction of a multi-storey building (as shown in Figure 1) and the second in a mechanical engineering context detailing the improvement of the design of a car (as shown in Figure 2). Both videos picture mathematics as a tool for dealing with real-world problems. These two videos may be accessed via Swinburne University of Technology's iTunes U presence, see links in the references (Civil engineering video 2013; Mechanical Engineering video 2013).

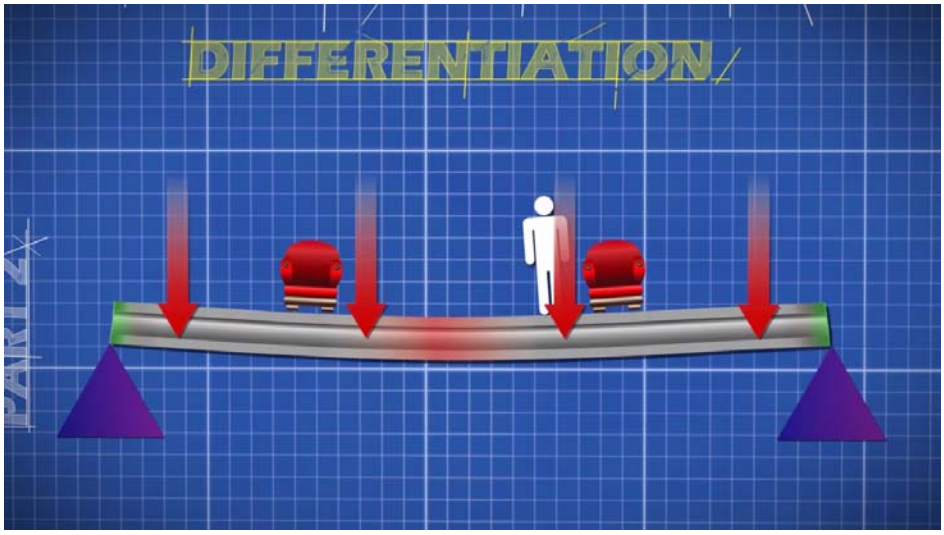

Figure 1: A screenshot of the civil engineering animation (Loch and Lamborn 2013)

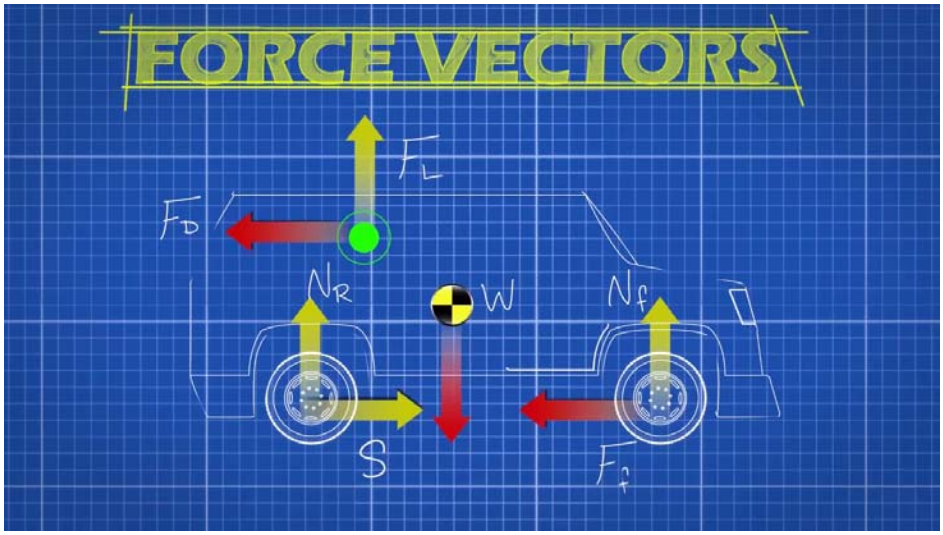

Figure 2: A screenshot of the mechanical engineering animation (Loch and Lamborn 2013)

The pilot of this project has just completed with the production of these videos. We have not yet been able to analyse the impact these videos have had on first year students, however

data collection has commenced. In this paper, we take a retrospective look at the first steps and decisions taken to establish the project. We hope that this paper will provide guidance to others on how to commence a similar project.

The research question addressed in this paper is

- What are the Critical Elements for a Successful Project to develop student-produced resources that demonstrate the relevance of maths?

This includes deciding on the form that this project would take, and what outcomes could be expected from such a project. In order to answer these questions, an analysis was undertaken examining the decisions that were made at the start of the first iteration and how the project was designed from the start. Qualitative data includes observations from the project team, communication with faculty senior management who funded the project, and a report produced by the engineering students at the conclusion of the pilot.

How the project was started

This project was lead jointly by a mathematician and an engineer, building on the recommendation made by Flegg *et al.* (2012) that mathematicians and the engineers should work more closely together to design mathematics units that were more relevant to engineering courses.

In addition, the approach was used that the suitable people to demonstrate the relevance of mathematics to first year engineering students are students who had actually gone through the first year units themselves recently: final year engineering students. These students had also completed the second and third year of their course and had applied their mathematical knowledge as their engineering skills developed and expanded. They could easily understand and highlight the mathematics topics that most first year students fail to realise connect to their later year studies. These final year students were also the best placed to think of approaches to interest first year level students in this important message, probably in ways better than academic staff could.

The decision was then made to apply to the Dean for funding to run a pilot project, commencing originally with one engineering discipline (civil engineering), however during the interview process for the engineering students, it was decided to expand this to civil and mechanical engineering for this pilot study. Initially it was thought just to use engineering students, however as further discussions took place regarding what the outcomes of this project could be, i.e. what resources could be created; it was decided to also include multi-media students. This then led to the award of scholarships to two successful engineering students and three multi-media students to undertake this work. As this was to be a pilot project (with the possibility of expansion later if the outcomes were successful), it was decided that at some stages of the project, the students involved would be interviewed to learn from previous experiences and to ensure that any possible expansion of this project would have the best framework in place to achieve the required outcomes. This would also allow reflection by the project team for what aspects of the project worked well and what did not. Note that student interviews have not yet been analysed.

The initial expectations were that students would create resources such as screen casts showing ‘mathematics in action’. It was felt that the decision of what sort of resources should be developed would be better decided by the students, on what would work best and what approach they should take. The students would be working closely with the project leaders throughout the pilot. Croft, Duah and Loch (2013) in their paper on students producing screencasts, concluded that students could make a valuable contribution to developing resource material that their peers will access. A more detailed discussion on the student perspective of creating resources for their peers in this project is presented in (Loch and Lamborn 2013). That paper provides the initial investigation of what actually happened during the project and how the students collaborated. We now extract the critical elements for a successful project.

The critical elements

Senior Leadership Support

We found that securing support early on from senior management in the form of funding and commitment to the project outcomes was fundamental to the project going ahead, and to the motivation of team members. This also meant that at least on paper time allocation was provided for the leaders. On the other hand, there was pressure to deliver however; this was more motivating than hindering progress for students and staff.

Staff Involvement

The composition of the project leadership team was important, as the skills from both engineering and mathematics were required. It is vital to approach such a project in a collaborative way and this ensured that a quality outcome was achieved. The involvement of the mathematician meant that this was not an engineering project but there was buy-in from mathematics. It also ensured that the mathematics applied by the students was correct. On the other hand, the involvement of the engineer guaranteed appropriate application of the mathematics in engineering contexts.

Student Selection

The selection of the right students was critical to the outcome. First of all, the engineering students from different disciplines had to be open to working across engineering discipline, and working with multi-media students with a complete different background. The two engineering students were selected on the basis of their innovative ideas and excellent communication skills that they demonstrated in their interviews for this project. This included a PowerPoint presentation on how to make maths relevant to first years.

Also, equally important, was the selection of the multi-media students. It was beneficial for the project that the three students had already worked as a team for their final year project, and they knew which skills each brought into the project.

In interviews, both groups of students commented that they had learnt from each other. The project has showed the engineers ways to apply their engineering knowledge that they had not ever considered. While the engineering students had thought of some ideas regarding the sort of resources that could be produced, these changed once the multi-media students joined the group and provided practical advice on what could be produced in a reasonable amount of time. From this initial discussion, the idea of producing animations emerged. The engineers realised that to make a video that would attract first year students, it needed to tell a story and not just be a collection of mathematical concepts. The multi-media students guided the engineering students towards development of storyboards, something the engineers would not have thought of. On the other hand, the engineers were the providers of the content for the videos. This combination of expertise across the two fields of engineering and multi-media creation was crucial for a high quality production, as commented on by all students. In fact, analysis of student comments in the final report indicate that it is critical if multi-media material is to be produced that technical expertise is included in the production team.

In addition, students believed that their perspective is important and that undergraduate engineering students should be involved in the production team. In their final report on this project the engineering students stated that:

> *First and foremost, the products are created by students. This is a critical element to ensure that the project was run from the mindset of a student, significantly increasing the chances of a positive reception. It is believed that for this program to be a success, it needs input at the very beginning from students.*

Marketing

Any production of multi-media material that could be of potential value for marketing purposes requires the full involvement of university marketing teams at the time of production. While the multi-media students had received instructions from marketing, there appeared to be disagreement once the videos had been finalised on how to brand the videos and whose names were allowed to be listed. For instance, the name of the multi-media production company the multi-media students had founded was only included after strong persistence from the project leaders. As a consequence, the intro and final frames of the video had to be redone to conform with branding guidelines. Such details need to be sorted out at the start of production, in collaboration between students, project leaders and marketing.

Technology

Providing the students with suitable technology had a positive impact on the outcome of the project. The use of tablet PCs for brainstorming and the creation of storyboards enabled the students to share their ideas on line and keep track of all the ideas and approaches they had covered. Students created digital notes and work from the outset, which they could easily share between them (Loch and Lamborn 2013).

While all five students were allocated a working space in the same room to enable them to work together, only the engineering students were working there. The multi-media students were working from home, where they had the required animation and sound production technology and software. This was not available in the engineering faculty. They came into the university only when meetings had been organised. One lesson for the future is to provide appropriate computer equipment in the shared working space so all students can work together face to face for the duration of the project.

Summary of key elements and future directions

The Critical Elements for a successful project to demonstrate the relevance of maths are:

- Support from senior management
- A multi-disciplinary team to lead the project
- Carefully selected final year engineering students and multi-media students
- Close collaboration with marketing
- A shared working space with professional multi-media equipment

This project showed that students can work collaboratively with staff in the production of resources for other students and produce a high quality outcome. As a result of the success of the pilot, the production of resources has now received continued funding to demonstrate the relevance of mathematics to all engineering discipline in the faculty. The approach analysed in this paper will be used again for the next round. In other words, the make-up of the production team will include engineering and mathematics staff, as well as engineering students and appropriate technical expertise. At this stage it is not clear what the type of resource will be that the students will produce, as this depends very much on the expertise the multi-media students are bringing.

This paper has only reported on one aspect of this project – the elements that were critical to make this project a success. We have written elsewhere about how the students have collaborated (Loch and Lamborn 2013). The next steps will be to undertake an evaluation of the videos, and an analysis of the interviews with students. We will also further investigate how first year students react to the videos, and how the videos could be improved. At this stage, the videos have been played during Open Day, but they have not yet been integrated in first year mathematics classes. How this will be done, and with what success, is what we will report on at AAEE 2014.

We will show both videos at this year's AAEE conference; however the reader may access them directly via Swinburne's iTunes U site (Civil Engineering Video 2013; Mechanical Engineering Video 2013).

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