The steam generator project – The development of key competencies in first year engineering physics students in Guangxi, China

James Mackay

Wellington Institute of Technology, New Zealand

Abstract

Project based learning is common in engineering education and is often used to develop core competencies of content knowledge, design and process skills necessary to be engineers. In this paper, I describe the implementation of a project based physics foundation module in Guangxi, China. Central to the design of the module was the construction of a simple steam generator that combined core content with an introduction to experimental physics as well as mechanical design. In the project, students, who were all second language speakers of English, were expected to construct and test a steam generator. This process required them to use conceptual knowledge as well as design and process skills. The main purpose of the project, however, was to address the development of English language, something that was necessary for the students to later study engineering in New Zealand. Initially, this was done through a vocabulary acquisition system that was used to build the vocabulary needed for the reports the students needed to write for the project later on. Key conceptual knowledge was addressed as the project unfolded, as were the necessary skills needed to make the generator. To investigate the effectiveness of the process, a case study approach was used to evaluate the performance of the students. Findings indicate that the project was successful in developing a strong community of practice and in particular that it had a positive effect on the students' acquisition of engineering English.

Keywords: Curriculum development; Engineering; Project Based Learning; Community of practice, Content based language learning

Corresponding author e-mail address: james.Mackay@WelTec.ac.nz

Introduction

The micro-steam engine has been used as a design project for students starting their studies in engineering in South Africa for more than two decades since the early 1990s and according to Bindon (1997), the project was "found by accident, rather than intent to involve all aspects of the profession". By this, he meant that the project taught both design as well as substantial theoretical aspects necessary for conceptualizing as well as carrying out a real mechanical engineering project to completion. The project itself is novel in that at the time of conception, little had been done in terms of providing students with opportunities to do some "real" (and messy) engineering with cheap, recyclable materials that are pretty much available to anybody. In this project, the final artifact is designed to be built under rural conditions with no access to electricity and so its very conception as a project has from this point of view an emancipatory aspect to it.

This paper outlines the use of the project in developing key competencies in physics of students studying engineering at a polytechnic in Guangxi, China. These students had completed a year of study in construction engineering in China and were preparing to complete their diplomas at a similar polytechnic in New Zealand. Being able to communicate in English is critical for these students and so while the project is traditionally used to induct students into the design process in engineering, as well as develop much needed process skills and teach key physics concepts, its main use in this context was to introduce students to the language of engineering physics in English. As an induction into the profession, the project can also play a pivotal role in helping students who are uncertain of their abilities in physics and engineering to see that they can actually "be an engineer" and help them to decide whether or not engineering is for them. In describing the many different roles this particular project can play in the engineering curriculum, I will draw on previous studies carried out by myself and others as well as current literature on teaching and learning engineering physics.

Project based learning

Project based learning has long been a characteristic of engineering education. In this project, students are introduced to many aspects of engineering through the building of a micro-steam generator. In order to achieve the final outcome of the project (which is a steam turbine generator that actually lights up an LED), students need to pick up a number of engineering focused practical skills, such as soldering, methodical work habits and meticulously attention to detail, while working with others in teams. They must also learn to communicate using engineering English and understand the conceptual nuances of the design of the generator from a conceptual point of view. More importantly for a novice engineer, learning in an authentic context provides the student with the opportunity to "try out" the identity of being an engineer and for the class as a whole to develop an engineering community of practice.

Using projects as the focus for learning also allows students to conduct investigations into a range of topics in basic physics that are related to a particular context. This contextualisation of learning has been shown by some researchers to help students' better deal with conceptual development rather than traditional non-contextualised approaches do (Linder, 1993). Through the construction of a meaningful artefact, learners are able to develop their content knowledge to deeper levels than they normally do (Harris & Katz, 2001) and in addition they are able to develop a number of important process skills as well as key literacies such as engineering report writing and the reading of engineering and scientific texts.

The Steam generator project

The Steam Generator project has been used many times by the author as a way to induct students into engineering physics and on these occasions, where the students are predominantly English speaking, the main purpose was to develop key academic competencies specifically in foundational physics and mathematics, as well as to induct the students into an engineering community of practice.

Central to the development of conceptual knowledge, is an enquiry based approach where students are helped to find things out for themselves, design and conduct experiments and analyse, interpret and represent data in an effective manner. Relevant mathematics and physics content knowledge is integrated into the programme, while at the same time requiring the students to design, make and test a steam engine and convert it into a generator. In the learning design, diagnostic tests (The Force Concept Inventory and Mechanics Baseline Test (Hestenes, D., Wells, M. & Swackhamer, G., 1992; Hestenes, D. & Wells, M., 1992)) were used to identify conceptual difficulties and these were ameliorated using a combination of practical and theoretical interventions, as well as computer simulations in a semi blended learning environment. The Diagnostic tests were used as both pre and posttests.

Curriculum Design

Figure 1 shows a schematic diagram of the different components of the course, which includes the development of understanding of core physics conceptual knowledge, process skills in both Physics as an experimental discipline and Engineering, the literacy practices associated with Engineering and some core mathematical knowledge. All this knowledge is taught through construction and improvement of a steam generator that is made from recycled tin cans and bits of metal, an example of which is shown in figure 2. While key academic competencies as mentioned above were addressed, in applying this project to the cohort of students from Guangxi, language acquisition and development in the context of engineering was considered to be of higher importance than the development of cxonceptual knowledge and the acquisition of process skills. In that sense, the project has been repurposed for use with the Guangxi students.

Figure 1: Curriculum elements of the course plan

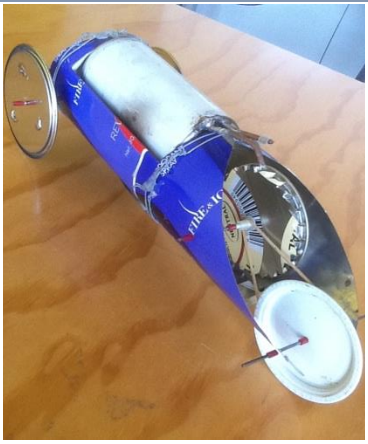


Figure 2: Steam Car

All content, skills and language development was planned around the project with short diversions into formal teaching of key concepts taking place only when they were seen to be necessary for the project to progress properly. Similarly, language work was integrated into the project work so that the students were constantly developing their language skills through reading, discussing, presenting and writing. Many of the students lacked particular process skills which were then taught as and when they were required ion an individual basis. The duration of the course was 8 x 6 hour days. In Guangxi 16 students participated in the project, none of whom were initially proficient in English to the extent that they were able to study engineering in English. The sequence of tasks in the project is outlined in table 1 below:

Table 1: Sequence of tasks

TASK (s)	**Skills developed / knowledge gained.**	**Schedule**
Build the car from kit form	Engineering process skills (Cutting, shaping, measuring etc.) Develop ability to read engineering language at a basic level	Days 1 & 2: Students work on individual projects, but as a group. Pictorial PowerPoint of instructions and instructions given in English
Theory in Physics	Learn about basic thermal interaction & mechanics (motion)	Days 1 & 2: series of short lectures given on the physics principles that underpin the steam engine.
Testing & measurement of efficiency of a component of the car	Physics laboratory skills, measurement, collection and interpretation of data	Day 3: Get the car to work and test its efficiency
Design & make a modification to improve the efficiency	Engineering process skills	Days 4 & 5: Design and make a modification to improve efficiency
Re-test the efficiency to see if there had been an improvement	Physics laboratory skills, measurement, collection and interpretation of data	Days 4 & 5: Retest the efficiency of the car
Convert the steam car to a steam generator	Design & make skills	Days 5 & 6: design and make a steam generator
Theory in Physics	Learn about Electricity and Magnetism	Day 5: short lecture on electricity generation Day 6: Short lecture on connecting generators in series

Write a report in English	Development of basic writing in science and engineering	Day 7: help given in report writing and the preparation of the PowerPoint presentations
PowerPoint Presentation in both Chinese and English	Develops speaking skills in English	Day 8: Presentations given and assessed by students as well as a panel of staff members

Constructing Science Knowledge

Underpinning the learning of science content knowledge in this programme, is the theory of constructivism and a conceptual change approach to learning science (Novak, 2002), which has been used to inform the design of the learning activities. There has been some debate around factors that affect success in tertiary study, with some research indicating that for science disciplines at any rate, conceptual development prior to university entrance is the most important factor (Everitt & Robins, 1991; Evans, M., 1999) , however, more recent studies (Engler, 2010), suggest that success in engineering is not associated with particular subjects taken at school but rather more with other factors such as being part of a community. This is supported by Madjar, McKinley, Deynzer, & Van Der Merwe (2010) who have suggested that affective more than cognitive factors play a greater role in student success in degree study. While the conceptual development of key ideas in the core content areas is important, this curriculum has a greater focus on the development of process skills, key literacies and a sense of being an engineer. Project based work is ideal for this situation in that it creates a flexible learning context through which an engineering community of practice as well as different scientific concepts can be developed (Harris, J. H.& Katz, L.G. 2001). In this course, the construction, modification and testing of a steam car was the project through which the physics concepts of energy, thermal interactions, motion and electricity and magnetism were learned.

The results of a previous study (Mackay, Pitawala, Carnegie & Watterson 2011), on the effectiveness of using the steam generator project to induct first year students into engineering show success in preparing students for the academic rigour of the courses that followed, as well as in preparing them for being part of the engineering community. In the study, diagnostic tests such as the *Force Concept Inventory* (FCI) and the *Mechanics Baseline Test* (MBT) (Hestenes, D., Wells, M. & Swackhamer, G., 1992; Hestenes, D. & Wells, M., 1992) were used as both pre and post tests to measure conceptual development.

Comparison of the project group with those students in mechanical engineering who did not go through the steam generator project course was done by comparing the mean scores between the two groups using a t-test for significance at the 95% level of confidence for groups <30. The project students (n=16) were compared with the mainstream students (n= 36). This was for the pre and post force concept inventory (FCI) tests that give an indication of conceptual understanding of the physics subject matter that was taught (The MBT was not used as a comparison tool due to gaps in the data record of the administration of that test. In that study, the first comparison of the means shows that there was no difference statistically between the two groups on the pre-test [$t(50) = 0.72$, $p < 0.05$]; however, it appears that those students who had gone through the project course responded better to instruction than did those who had not, as there was a significant difference between the two groups on the post-test, with the project students outperforming the mainstream students [$t(50) = 2.41$, $p < 0.05$]. Given that the project students were initially selected from a pool of students who did not qualify for automatic entry into the diploma, this was seen to be a good result.

With the Guangxi students, content in the project was developed in such a way that thermal physics naturally led onto basic mechanics which then led onto electricity and magnetism. This mirrored the progression of the project from building the boiler and turbine (thermal physics) to testing the efficiency (using mechanics) to designing the generator (electricity and magnetism). This close alignment between the natural progression of the topics and the stages in the building of the generators was mentioned by students as being helpful in understanding the concepts.

Developing Content based literacy

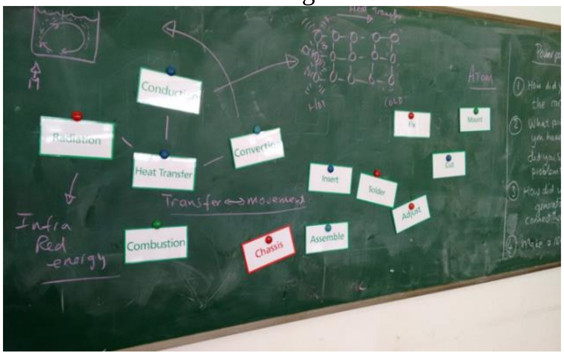
Historically, teaching reading and writing to develop academic literacy has evolved from study skills based courses that focus on decontextualized technical aspects of reading and writing, not related to any particular discipline, to courses where the reading and writing is situated within particular disciplines. The academic skills approach is perhaps easier to implement however it fails to address the fundamental issue of socialising the student into academic life. By writing and reading for a broader academic purpose, students can become acculturated into a generic academic life, but as Street (2004) point out, this approach fails to recognise that knowledge is constructed in different ways by different disciplines.

The development of writing and reading skills within the context of a particular discipline is important for developing the technical aspects of writing that are peculiar to a discipline. It also has the advantage of inducting students into a discourse community based on that discipline. This genre based approach to teaching academic literacy is best done by using facilitators who are "insiders" in the discourse communities (Gee 2001, in Jacobs, 2005). Using this academic literacies approach looks at language as not only being part of the discipline, but part of a wider community of practice.

In this curriculum, two literacy events were planned. The first was the writing of a short report in English on the testing and development of the modification they made as part of the project and the second was a bilingual (Chinese and English) presentation about the success of their project at the end of the course.

In order to facilitate vocabulary acquisition throughout the course, a patented method of vocabulary acquisition through the use of flash cards and concept maps that has been developed by a company in the United States (Concept Construxions http://educhange.com/) was used. Language work was continuously being built on and the cards were relied on throughout the board discussions of the content in the project. This was particularly helpful for 16 second language speakers of English in Guangxi, who indicated in formal feedback that the development of language in this way, by linking vocabulary to concepts was particularly helpful to them. This was further supported by post project interviews with the students after six months of study in New Zealand, where

12 of the 16 managed to improve their English sufficiently to be allowed to study engineering in English. For all, their initial introduction to engineering English was through the steam generator project. The vocabulary acquisition flash card system developed for the project by Concept Construxions is shown in Figure 3.



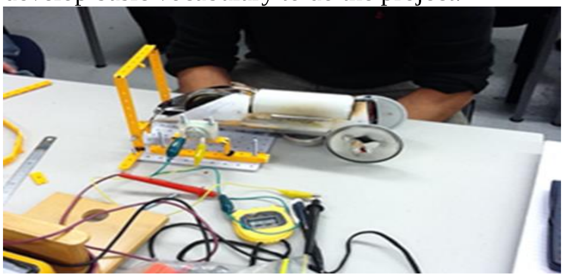
Developing a sense of being an engineer

Developing communities of practice is linked closely with the development of discourses that are appropriate for the different disciplines and professions. Much modern research suggests that affective factors, more than cognitive factors play a greater role in student success in degree study (Madjar, McKinley, Deynzer, & Van Der Merwe, 2010). To this end, the model design has shifted focus to include a greater emphasis on affective factors that will include and develop student's sense of community and identity in their chosen field, engineering.

Different communities of practice draw on different learning domains to a greater or lesser extent and also in different ways. For example it could be that those students who are going into engineering would draw more on the psychomotor domain that say those going into pure science. This would be particularly true of students at a polytechnic as compared with those enrolled in university degrees. In addition, many engineering projects require skills used that are slightly different to those needed in the study of science. Using Blooms Taxonomy as a guide to designing activities highlights the differences in the nature of the process skills learned by different communities of practice.

In this project students are required to grapple with real engineering problems in making their machine efficient enough to generate enough electricity to light up an LED. In fact this is quite a difficult task in that the machine at optimum efficient with the DC motors that have been provided, will only generate 0.6 volts, not nearly sufficient to light up a single LED. This means that they need to find a way to develop more power, a solution they have to come up with.

Student feedback has suggested that this project has for some students played a pivotal role in the way they have started to see themselves. Student responses to the project were gauged in two ways, the first was through a post course questionnaire probing student attitudes and the second was by interviewing six selected students after the project had been completed. Interviews revealed that the students from the Guangxi group rated the course highly (4.5 / 5.0, 5 being very happy with the project course and 1 being the least happy). Specific comments were made regarding the usefulness of the concept map flash card system in helping them develop basic vocabulary to do the project.



Conclusion

In conclusion, we see the course as being successful, not only in preparing students for their first year of the diploma programme, but also in inducting students into the engineering community through the use of content based literacy activities but also through realistic engineering project work. Finally, the steam car project showed us that project based learning can help to develop a deeper understanding of physics concepts required for engineering and in addition, it also plays a major role in developing the literacy practices needed to operate successfully in the engineering community. Since the implementation of this project at WelTec, there have been a number of other project based courses implemented in engineering. This course also played a role in the decisions made by those students who decided not to pursue engineering.

In addition to the core content that was learned, several key competencies were acquired by the students, including an ability to communicate and learn the literacy practices of the engineering community, important science and engineering process skills as well as a sense of using their own initiative to solve problems. Evidence collected revealed that the steam generator project played an important role in helping those students who went on to study engineering to identify themselves as engineers and feel part of the scientific and engineering community.

References

Bindon, J.P. (1997). The micro Steam Car, a practical and theoretical design project. *International Journal of Mechanical Engineering Education*, 27(3):181-194.

Engler, R. (2010). *Are particular school subjects associated with better performance at university*? Wellington: Ministry of Education.

Evans, M. (1999). School-leavers' transition to tertiary study: a literature review, Working paper 3/99, Department of Econometrics and business statistics, Melbourne: Monash University.

Everett, J. E., & Robins, J. (1991). Tertiary Entrance Predictors of First-Year University Performance, *Australian Journal of Education*, 35(1), 24-40.

Harris, J. H.& Katz, L.G. (2001). *Young Investigators: The project approach in the early years*. New York

Hestenes, D., Wells, M. & Swackhamer, G., (1992). 'Force Concept Inventory', *The Physics Teacher*, 30, pp.141-158.

Hestenes, D. & Wells, M., (1992). 'A Mechanics Baseline Test', *The Physics Teacher*, 30, pp. 159-166.

Jacobs C (2005) On being an insider on the outside:new spaces for integrating academic literacies. *Teaching in Higher Education* Vol. 10, No. 4, October 2005, pp. 475_/487

Linder, C.J. (1993). A Challenge to Conceptual Change. *Science Education* . 77(3): 293-300.

Mackay, J., Lock, M., Pitawala, S., Carnegie, D.& Watterson, C. (2011). Inducting Students into the Engineering Community: A case study of the development of a project based engineering foundation programme. *NZARE Conference, Tauranga, New Zealand (December 2011)*

Madjar, I., McKinley, E., Deynzer, M., & Van Der Merwe, A. (2010). *Stumbling blocks or stepping stones? Students' experience of transition from low-mid decile schools to university, Auckland: Starpath project*, The University of Auckland.

Novak, J. D. (2002). Meaningful Learning: The Essential Factor for Conceptual Change in Limited or Inappropriate Propositional Hierarchies Leading to Empowerment of Learners. *Science Education*, 86, pp. 548-571

Street (2004) Academic literacies and the 'new orders': implications for research and practice in student writing in higher education. *Learning and Teaching in the Social Sciences* Volume 1 Number 1.