Embedding Authentic Practice Based Learning in Engineering Undergraduate Courses

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C2: Interdisciplinary and cross-disciplinary engineering programs and learning environments

CONTEXT Authentic education, which connects the lessons with students' real lives and their prior knowledge, has the potential to create meaningful learning environments in which students see their lessons as meaningful, useful and relevant. Typically engineering undergraduate courses do not provide students with an opportunity to solve meaningful real life engineering problems that are beneficial for their lives and societies. Authentic engineering education has the potential to help students develop their creativity, problem solving and innovation skills.

PURPOSE The focus of authentic education is to employ interdisciplinary ways in order to solve real-world problems. This study aims at inspiring other educators to integrate authentic scenarios into their teaching activities.

APPROACH For this study projects and assignments with real life relevance were introduced for several courses across a semester for students enrolled in papers spanning a range of years and engineering disciplines. Students comments on their learning experience with this authentic approach vs. traditional lecture based teaching are included in this paper.

RESULTS Early observations indicate an increased level of engagement with students more motivated to learn and displaying an enthusiastic positive approach to their study. It is also considerably more exciting and stimulating environment to teach in.

CONCLUSIONS This paper outlines relatively early efforts to change the established learning paradigm in engineering classes and as such it is too early to draw firm conclusions. However, our experiences to date demonstrate that providing a more authentic education environment engages students more positively in their study. Creating such an environment connects theory and practice and exposes students to real life situations and should prepare them better for 21st century challenges.

KEYWORDS Real World Problems, Authentic Learning, Self-Directed Learning

Introduction

The new pedagogical concept called "authentic learning' was proposed by Herrington et al (Herrington, 2006). Authentic learning typically relates to real world, complex problems and their solutions, using role playing exercises, problem-based activities in real or simulated communities of practice. Herod (Herod, 2002) describes authentic learning as follows:

> "*In this type of learning materials and activities are framed around real life contexts in which they would be used. The underlying assumptions of this approach is that material is meaningful to students and therefore, more motivating and deeply processed."*

It is reported that students engaged in authentic learning activities cultivate "portable skills" and develop the flexibility to work across disciplinary and cultural boundaries to generate innovative solutions (Chang et al., 2010).

The process of authentic learning creates an interdisciplinary approach to providing solutions to real life problems that students relate to and are motivated to learn skills that better prepare them better for the Grand Challenges (Vest, 2008) they will encounter in their careers and lives after leaving university (Jadud, 2000).

Typical traditional engineering courses often do not provide students with an opportunity to solve meaningful real life engineering problems that are beneficial for their lives and societies. It has also been around fifty years since the engineering curricula has changed significantly. Since this time science and mathematics has had a central and dominant emphasis in most engineering courses. However much has changed in this time and a modern engineer requires a broader set of skills. In recent years many employers have complained about the need for new engineering graduates to have more professional skills (Miller, 2010).

As Richard Miller of Olin College, USA reports many modern students are highly motivated to tackle the Grand Challenges referred to by (Vest, 2008) but do not see the narrow study of physics and mathematics to be the key to tackling these problems. They are often seeking to make a positive difference in the world and the lives of people. They also do not see the study of engineering science and mathematics as being directly related to the problems that they see or care about (Miller, 2010). Miller argues that engineering curricula need rebalancing and requires students to be more involved in "maker" projects less time spent in lectures that involve learning just in case knowledge about topics that are never actually needed.

Higher education is beginning to shift, but slowly. The old pedagogical paradigm of the expert professor delivering content to rows and rows of quiet students who take notes and prepare to demonstrate knowledge in tests is beginning to change. Now we can see the emergence of more experiential learning in engineering courses worldwide. These developments in engineering education are leading to fundamental changes in curricula and pedagogies (Kolmos et al., 2004)

There is much evidence that instructional strategies that encourage undergraduates to become actively engaged in their own learning can produce levels of understanding, retention and transfer of knowledge greater than those resulting from traditional lecture/lab classes (Lord, 1997), however in many science and technology subjects there has been little adoption of student centric practices (DeHaan, 2005) despite evidence that the "sage on a stage" approach (King, 1993) is not as effective as alternatives. Developments in student-centric learning such as problem-based and project-based learning have so far had relatively little impact on mainstream engineering education (Mills and Treagust, 2003), this could in part be attributed to a lack of understanding of the difference between these approaches, particularly when a project-based approach is mistakenly represented as problem-based. It is not uncommon for project-based approaches to be based around specifications for a desired end product, and such fixed expectations can diminish the learner's role in setting the goals and outcomes (Savery, 2015). Whilst student-centric approaches are gaining popularity in STEM subjects, the liberal arts disciplines were early adopters of such approaches. It has been argued that engineering and technology should be reconfigured as academic disciplines, similar to other liberal arts disciplines (Duderstadt, 2010). Whilst this view is gaining some support many universities and professional institutes remain sceptical and wedded to a more traditional approach.

Traditional engineering instruction is deductive, beginning with theories and progressing to the applications of those theories (Prince and Felder, 2006), whereas arts based pedagogies are more inductive. Topics are introduced by presenting specific observations, case studies or problems, and theories are taught or the students are helped to discover them only after the need to know them has been established. A wide variety of inductive teaching methods exist, including inquiry learning, problem-based learning, project-based learning and discovery learning. The mismatch that exists between common learning styles of engineering students and traditional teaching styles of engineering professors is not a recent observation (Felder and Silverman, 1988) which begs the question, why has there been no widespread adoption of inductive teaching methods in the engineering disciplines? In engineering, the most-favoured pedagogical model for teaching in an inductive style is project-based learning (Dym et al., 2005). Project based learning is an approach to learning that focuses on developing a product or the creation of an artefact of some form. Whilst not formally defined as such, project based learning has the potential to embrace the principles of learning by doing (Schank et al., 1999), though the project may or may not be student-centred, problem-based, or inquiry-based as has been observed by de Graaf and Kolmos (De Graaf and Kolmos, 2003) who define three types of projects that differ in the degree of student autonomy.

1. Task based project: Student teams work on projects that have been defined by the instructor, using largely instructor-prescribed methods. This type of project provides minimal student motivation and skill development, and is part of traditional instruction in most engineering curricula.
2. Project based learning: The instructor defines the subject area of the projects and specifies in general terms the approaches to be used (which normally involve methods common in the discipline of the subject area), but the students identify the specific project and design the particular approach they will take to complete it.
3. Problem based learning: The students have nearly complete autonomy to choose their project and their approach to it.

Much has been written on the third of these, namely problem based learning (Kolmos et al., 2004).

Real authentic learning is a further development of problem based learning. (Grabinger et al., 1997). Authenticity is an important part of problem based learning for three reasons. First, realistic problems hold more relevance to students' needs and experiences because students can relate what they are learning to problems and goals that they see every day. Secondly because students encounter during learning are authentic and reflect the true challenges of real world problems leading to a deeper learning. Thirdly because solutions to really complex problems benefit from a group or team approach that opportunities for the students to the learn communication, collaborative and presentation skills required of a modern engineer.

Students acquire content and skills through the resolution of realistic problems. Understandings that are developed in their realistic and complex situations are more easily retrieved when needed (Brown et al., 1989).

The objective of incorporating work experience into an engineering degree programme is widely accepted as a worthy direction but its application has proved to be quite difficult in practice. Other alternatives include, Gap Year, which provides a year of work prior to education programme starting and can provide a challenging and exciting experience attracting students into engineering.

Another method of integrated work experience is the sandwich degree in which periods of work experience are alternated with periods of study. (Blackwell et al., 2001). Yet despite the advantages of sandwich degrees, there has been a steady fall in the numbers enrolling on such courses. But why don't more universities offer placement years – and in a broader range of courses?

Employers' reluctance to spend time supervising students is partly to blame, says Warwick University professor Kate Purcell (Purcell and Tzanakou, 2016) who also observes that,

"Work placements are very difficult for universities to set up and they're expensive for to run – departments have to arrange visits by academics, and mentoring, to ensure students are having a rewarding experience."

Integrated semesters of work experience where universities utilise a three semester per year system to better utilise their staff and facilities and use the extra semester for work related projects (Blair et al., 2004).

Authentic problem based learning requires a shift in the traditional roles of students and lecturers. Teachers become facilitators and tutors of the learning process rather than presenters of knowledge. Students become self-directed learners and problem solvers (Grabinger et al., 1997).

This paper therefore suggests that a new model of engineering education is needed. Whilst the lecture plus tutorial model has some advantages, the authors experience is that students are turning away from lectures, which they find too boring. They need more flexible ways of learning engineering and demonstrating engineering expertise. This paper draws on experiences integrating such approaches in a broader educational context and proposes a radically different socio-technical and more authentic approach.

Our Experiences

The experiences of the authors of this paper are different. Each has come through an alternative route, either involving a change of discipline, the teaching of engineers in a non-engineering subject or the involvement in teacher training that involves educators from a wide range of domains. Common to these experiences is exposure to different ways of thinking and approaching education that has resulted in a belief that engineering education can be different. In particular, all of the authors feel that the core pedagogic values of the arts disciplines can play an important role in STEM subjects (Connor et al., 2014). These values place the student at the heart of the learning experience and support the student in terms of defining their own learning journey, which becomes a vehicle for introducing disciplinary knowledge. The next section presents case study projects that demonstrate the effectiveness of more inductive approaches to education for engineering and design. These case studies are taken from different schools within the Faculty of Design and Creative technologies. They are taken from varying stages of the curriculum from first year through to final year and masters studies.

Auckland University of Technology (AUT) offers a number of accredited degree options including 4-year Bachelor of Engineering (BE) degrees (aligned the Washington Accord) and 3-year Bachelor of Engineering Technology (BEngTech) degrees (in line with the Sydney Accord), across a range of disciplines, including mechanical, electrical and built environment engineering. In offering these programmes, AUT has framed itself as a contemporary university with a distinctive approach to teaching and learning. It has a vision of providing student-centred, innovative and responsive learning experiences.

Around six years ago we undertook a major curriculum development In line with this vision. The spine of the new curriculum was design based with three group design projects running through the programme. (One of these design projects is included in the case studies). All of these design projects were based around a loosely defined problem that gave the students ample scope to research and consolidate their previously acquired technical skills in a simulated authentic situation.

Developing a new curriculum is quite a challenge, it is a difficult system problem and real complete transformation can only be achieved by having all the following elements satisfied (Kolmos et al., 2004)

- Vision
- Consensus
- Skills
- Incentives
- Resources
- Action plan

We cannot honestly state that all of these have been met fully yet at Auckland University of Technology, however there is certainly a vision and this has been confirmed by substantial investment in new teaching environments including ‘maker’ spaces and collaborative spaces similar to those students will experience outside of university.

Most of the academic staff have been open to change and have responded positively. There are some staff that are a little resistant and continue to ‘teach’ in outdated fashion.

More could have been done to prepare academic staff for the transformation but programmes are now in place to develop the additional skills required. All new academic staff are required to undertake some education training within the first two years of joining. Workspaces for new student centric teaching have been provided with more currently being built.

In terms of human resources it is fair to say they have been stretched. Ultimately more authentic problem based learning should, in time, free up lecturer capacity previously used in third and fourth year lectures and tutorials. So far this has not been evident.

It has been common practice in most engineering degree programmes to have a final year project but most of the teaching up until the final year had been subject based with students answering artificial text book questions style questions. The authors of this paper decided to experiment with using authentic case studies immersing students in realistic situations that could encourage a deeper learning. The rationale behind this approach is based on work by (Jonassen, 1999) who described a model for a learning environment based on constructivist principles, which provides a framework for using cases to support authentic activities. The model centres on a focal learning activity, which may be a project, problem or case the learner must solve or resolve.

(Anderson et al., 2014) argue that a case study method of teaching develops students' critical thinking skills. (Montpetit and Kajiura, 2012) argue that “*Case based authentic teaching and learning strategies can offer instructors effective pedagogical tools to scaffold learning through activities designed to fulfil teaching objectives and desired student learning outcomes”*

(Anderson et al., 2014) however do have some reservations and highlight that these methods can be “scary and challenging” for instructors and also that they can time consuming and more work initially than traditional lectures. Our experience has been that whilst the initial work in researching and setting up authentic cases increases, the time spent in formal lectures has decreased and student motivation to learn has increased.

The following case studies highlight a number of ways that cover the same skills to be learnt but in a more authentic way.

Case One Engineers Without Borders (EWB)

The EWB project is part of the 'Introduction to Design' course which is a core course for both the Bachelor of Engineering Technology and Bachelor of Engineering (Honours) degrees first year first semester at Auckland University of Technology. The course develops effective communication skills in an engineering design context, using a variety of media. It further develops an understanding of the role and responsibilities of an engineer in society. The pedagogy used for this course is different to that of traditional engineering subjects where students passively receive information from the lecturer. Overall the approach is one of active learning. The design element is essentially covered by students completing tutorial problems individually or in groups with the aid of a facilitator, essentially a variation on the studio-based learning approach. The EWB Challenge could be considered either as an authentic project based learning, problem based learning or inquiry based learning. Certainly, it is intended as a project based learning framework driven by a poorly defined problem statement. However, for most of the groups this authentic problem based learning stimulated a deeper engagement that enabled these teams to transition in to an inquiry based learning mode as their interest and their commitment to the project developed. Certainly, the groups were encouraged to develop their projects in this way. Given there is general confusion about project based learning and problem based learning, this case study provides a useful opportunity to clarify how the various approaches are related. We consider problem based learning to be a subset of inquiry based learning, which itself is a subset of active learning (Spronken-Smith et al., 2008). However, not all problem based or inquiry based approaches are necessarily project based learning. Project based learning is another subset of active learning that overlaps with problem based learning. The EWB Challenge is a fantastic opportunity for students to learn about and understand different cultures and be involved in an exciting time of change for the region selected for that years challenge. A previous challenge was based on a rural hill top communities in the Gorkha District of Nepal. It presented an opportunity to learn, not just about the challenges facing their communities, but also about community development in general, and the role engineers and other technical professionals can play. Engineers without Borders (EWB) is working towards the goal of a transformed engineering sector so that every engineer has the skills, knowledge, experience and attitude to contribute towards sustainable community development and poverty alleviation. The EWB Challenge program aims to contribute to this broader goal by working at the university level to create change within engineering curriculum and help to shape future engineers by achieving the following objectives:

- Introduce first year engineering students to concepts of humanitarian engineering by working on real world development projects.
- Empower university students to gain an increased awareness of the role of engineers in poverty alleviation and their individual responsibility as global citizens.
- Support EWB's community based partner organisations work by providing access to engineering student design ideas and by supporting them to share knowledge and resources with universities internationally.

The students were asked to form groups of four and select a design area for their project. Design areas included but are not limited to housing & construction, water supply & sanitation systems, energy, waste management, climate change, information & communications technology or transportation. The groups provided design solutions for projects using the village of Sadhikhola as a case study. They could address a single issue or provide an integrated design solution for two or more areas, or even propose an alternative project. The EWB Challenge is an open-ended learning experience and the breadth and depth of design is left to the groups to decide. Throughout the project students were encouraged to be creative in their solutions and to document any assumptions in the final report. The project based learning activity was assessed in two ways. Firstly by a group presentation in which all members were expected to participate fully and secondly by way of a project report. A single group mark was awarded to all group members. Where a group member had not participated fully their mark was adjusted accordingly. Around 100 projects were completed. All were of good standard, some were exceptional. Some groups and individuals were extremely well motivated and developed valuable research skills preparing them well for life-long learning. Most of the students achieved learning outcomes that included critical thinking, ability for independent inquiry and the responsibility for own learning and intellectual growth. While no evidence proves that problem based learning enhances academic achievement as measured by exams, there is evidence to suggest that problem based learning "works" for achieving other important learning outcomes. Studies suggest that problem based learning develops more positive student attitudes, fosters a deeper approach to learning and helps students retain knowledge longer than traditional instruction. Further, just as cooperative learning provides a natural environment to promote interpersonal skills, project based learning provides a natural environment for developing problem-solving and life-long learning skills (Kolmos et al., 2004).

Case Two Authentic Design Based Learning Project Conveyor Belt Design

Here students were required to self-assign into teams of four, similar to what would be typical in a real life design office. Workspace office with computers etc. was made available to the students, again to simulate conditions that would encounter outside of university.

"Working as a team of four students, you are to assume the function of an engineering design company tasked with undertaking this design project. The client, the Salty-Dog Ltd, is located directly adjacent to the fishing wharfs at Castle Point and processes the brine-stored catch into a range of tasty products for export consumption into twelve countries. This company have requested that your design consultancy provide the fully detailed design for a continuous slat conveyor to transfer pallets of fish in brine from the loading bay into the fish-finger and whole fish fillet processing departments. These pallets are loaded into the conveyor and removed from the receiving table by hand. Your team's task is to design the power transmission system and supporting structures for the conveyor from prime mover to the head shaft and conveying medium. For the purposes of this project, the assembly drawing of the drive system may be schematic/pictorial, but the head-shaft drawing and means of bearing support must provide sufficient detail to enable manufacture of the shaft by a contract engineering shop. Detail of the supporting structure and guarding of the drive system is also required and consideration should be given to the conveyors operating loads and conditions during the design process as well as design for quality and reliability. The design report should be professional in its presentation to the customer and should include specifications of the drive system, supporting structure and a summary of supporting calculations for the design referenced as appropriate".

This project is an excellent illustration of how authentic problem based learning can replace the traditional lecture/tutorial model. The level of technical skills alone would have included advanced materials, advanced strength of materials and Computer Aided Design. Previously students would have generally been happy to just study enough to pass tests and examinations. Now they are motivated to learn and in a much deeper way.

In addition to the technical aspects of the project there are softer skills being acquired. The project requires an understanding of environmental, Social, ethical and legal requirements. Furthermore the requirement to work in a group promotes collaboration and communication skills that employers often say are lacking in engineering graduates.

Authentic assignments and situations

It is not necessary that all teaching be of the larger authentic project type. Many of the staff now frame questions or mini assignments in authentic situations replacing dry text book style questions with real situations that contain the subject skills to be acquired by the students. We cannot claim this to be a universal approach as yet but this is a growing trend. Two example case studies are used where the student is placed in the role of engineer/designer in an authentic work situation.

Smart Materials Assignment

The subject of so called SMART materials was previously covered in two separate papers. Advanced Production Systems and Advanced Materials by way of lectures. Both papers were taught separately and no effective link was made between the properties of these type of materials, how they could be manufactured in the future, sustainability issues and commercial possibilities.

Again students typically would try to remember only enough to 'get through' both papers. This assignment places the student in the role of engineer who has to investigate and report formally to their CEO.

Put yourself in the role of a Project Engineer of a fictitious Company. This Company can be based on an existing Company that has developed 'Smart Materials' into a product.

The CEO of your Company has heard something about these 'these so called smart materials'. He has little understanding of what they are and how they might benefit your Company. [Choose an Industry or Company]

He has asked you to prepare a report that explains what they are and how they could be used in future products for your Company.

Give details of the material properties.

You are asked to detail the possible applications applicable to your Company or Industry and the benefits they could bring.

You are expected to detail materials and processes involved.

You are expected to consider 'design for sustainability issues'

You should make recommendations on possible development of 'Smart' materials in your particular Company.

This should be produced in report format and be no more than 2000 words.

Case Four Design for Disability

The Design for Disability project is a semester long project undertaken by second year students majoring in mechatronics and is the backbone of the second year Mechatronics Design class. The class is designed around the observation that attempting to define mechatronics as simply the combination of different technologies is no longer sufficient to explain mechatronics and that in reality mechatronics solves technological problems using interdisciplinary knowledge. Rather than focusing on mechatronics from the bottom up combination of components, the class adopts a top down approach that focuses on systems engineering approaches and design thinking.

The Design for Disability project is open-ended, ambiguous and exhibits all of the characteristics of a real world design problem. Student teams are simply asked to design something that can improve quality of life for people with disability and are expected to undertake suitable problem framing (Dorst and Cross, 2001; Sosa et al., 2017) to not only define disability and quality of life, but to also provide an insight to potentially creative solutions. For example, students are encouraged to think beyond approaches to assistive living and instead consider projects that encourage societal change. Whilst not undertaken by students, an example of such a project would be a wheelchair simulator incorporating virtual reality technology to allow able-bodied people to experience the frustrations of being in a wheel chair as a means to change perceptions around disability.

The project aims to balance activation of students' creativity with systematic systems thinking and engineering design practice by leading students through periods of divergent and convergent thinking. The initial problem framing, essentially a creative activity, is immediate followed by the development of a formal requirements specification that embodies both user requirements and system requirements as a starting point for design activities as well as to encourage downstream activities relating to verification and validation of design solutions.

The assessment for this class has also been structured to be balanced across the three concepts of knowing, thinking and doing. The most significant assessment is the use of a blogging platform to record a design journal that shows the processes used to reach a solution to the brief, the rationale for all design decisions as well as to capture individual reflections on both the designed product and the design process.

At the time of writing, this first delivery of this class is still incomplete. However, positive student engagement with the delivery has been noted with high attendance and a large degree of interaction between staff and students that is verging on becoming an exercise in co-creation. Whilst some students had initial reservations on the ambiguity of the brief, others immediately accepted the different approach with comments on their blogs such as the following two observations:

> *"The structure of this paper was not expected but appreciated. It is refreshing to be in an environment that wants to change the norm; given that my aim is to be an interrupter, not just an innovator."*

> *"This class is the most exciting class in engineering so far. Mostly because we will be asked to embrace out creative side instead and not focus on the physics and the equation part of it. It will also challenge our perceptions of the role of the engineer in solving complex, open ended problems."*

In terms of successes to date, the class has successfully engaged students in an open-ended design task, however despite this success there is still room for further improvement. Whilst the design brief specifically encouraged teams to think beyond assistive living, there seems to have been some reticence on the part of the student teams to push the boundaries of the brief with all teams choosing to frame the problem in such a way that it produces an assistive device as an outcome. This is potentially as a result of a lack of confidence or concern over how a less orthodox framing could be received which is a potential disconnect from the intention to develop new "modes of thinking" that shift the traditional focus from teaching-by-transmission to a more socialised engagement with learning through creativity, collaboration (Connor et al., 2015).

Whilst the class has produced a high degree of engagement with the student cohort, there have been difficulties with the delivery particularly in terms of the effort required to maintain a robust and useful dialogue with the student teams through the project work. Arguably, the constant critique of student work through the online design journal would not scale to the large class sizes often associated with many first year classes.

Results and Discussion

There has been curriculum change that has resulted in design projects being at the core and running through the whole period of the degrees but much of this is not yet authentic learning. It is an improvement on the traditional curriculum but has not really gone far enough. This requires a change in mindset of academic staff and ideally is supported by a top down vision and support. However as identified by Kolmos et al. (2004) these changes are difficult and take time. It may need a different approach to academic staff recruitment with a change in emphasis from employing PhD research biased academics to some with real world experiences.

The case studies discussed in this paper indicate that a ‘bottom up’ approach can show immediate benefits. The authors of the paper did not wait to be told that they must change their approach to one of authentic learning.

This change in approach has been received favourably by students are shown by student comments in case four and also the following comments from final year student who has been with us as our approaches to course delivery have changed.

We are sure that our students are now graduating with an improved skill set that better equips them for their engineering careers than previously.

“During my time at University I felt that most courses assessed me in very much the same way. This was to set questions and exercises that immediately utilised an idea. Which was albeit a valid method to force a rule or concept into my head, however it always felt like after the course was over this information didn’t stick very well. My experience always felt like one task after another, to be completed, assessed and forgotten. In my experience the real life projects where I am given more freedom and agency to pursue a solution are enjoyable and I feel what I learned has stuck” [Final year BE Hons student]

Conclusions

It is too early to draw firm conclusions but our experiences to date suggest that providing a more authentic education environment has the potential to engage students more positively in their study. Creating such an environment connects theory and practice and exposes students to real life situations and should prepare them better for 21st century challenges.

Based on our anecdotal observations, it appears that authentic learning is allowing our students to relate target learning effectively through concrete experience and collaborations. Similarly, it appears that this approach motivates students in learning and provides an opportunity for students to use what they have learned in lectures, text books or from online sources and develop a deeper understanding of them and how they can be applied in future real life situations. Future work will consider a more systematic introduction of authentic learning approaches to produce more objective evidence to support these assertions.

This approach of framing learning in authentic situations is contagious and out ‘bottom up’ approach is gaining traction with many of the academic staff. Many are finding that after an initial input of time they are now experiencing a freeing up of contact hours that were previously spent covering final year advanced courses now find that authentic projects can be used for the student to acquire these skills much more effectively.

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