Experience with practical project based learning in a developing undergraduate engineering degree program

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Abstract **- The use of practical learning experience in undergraduate degree programs offers students the opportunity to apply their knowledge and receive feedback in a supportive environment before entering the workplace or undertaking further study. Traditional laboratory based instruction allows students this opportunity; however, it tends to provide limited opportunity for students to explore creative solutions to problem solving. The University of Waikato recently established undergraduate degree programs in engineering and has aimed to incorporate flexible learning opportunities for students, as part of their degree and as extra-curricular activities. This paper presents some of the practical project based opportunities that have been adopted and examines the role these have played in a developing engineering program.**

Key Words- project based learning, undergraduate degree

INTRODUCTION

Engineering in a university environment is a relatively modern concept, unlike medicine, philosophy or the sciences. Because of this there is still significant conjecture over how university based engineering education should be structured and the outcomes to be achieved during an engineering degree.

From a historical perspective, engineering draws it origins from the artisans. Technological developments would come through incremental progressions and refinement of ideas past from generation to generation. By modern day terminology, they would serve an apprenticeship of sorts.

The "modern" concept of university based engineering education started to develop in France in the late 18th century with the establishment of the Ecole Polytechnique. This saw students undertaking entrance examinations and being given a mathematical backing before moving into a specific field of engineering [1].

Building on the French system of mathematical rigor, the development of engineering schools in the USA in the mid 19th century saw a high emphasis placed not only on lecture based instruction but also hands on experience in laboratories [2].

One of the challenges to this approach, in recent times, has been the development of cheap computing technology and high level simulation software. There is a temptation to reduce the use of hands on instruction in favor of computer based simulation. The short coming of this approach is that students may miss the inadequacies of theory's ability to explain phenomena that can only be observed through hands on experience [3].

More importantly it has been suggested that these hands on experiences need to form a key part in developing understanding not only in the later years of an engineering program, but across the entire degree [3].

Further, as engineering is in effect the application of science to everyday or "real world" problems there must obviously be a degree of understanding of how engineering operates in such conditions. Employers want engineering graduates, who have good communication skills, an ability to function in a team as well as the obvious desire for sound analytical skills [4]. As such, in order to ensure successful graduate outcomes, it is in the interest of undergraduate degree programs to incorporate elements in to coursework that will enhance students' abilities in these areas.

The University of Waikato (UoW) has been offering undergraduate degree programs in engineering since 2000 and has attempted to achieve some employer needs through the use of practical projects across all years of the degree program. In these projects students are encouraged to explore solutions utilizing the tools that would be used by an engineer in practice such as CAD, CAM and FEM while still relating them to documented theory. The aim is to foster an atmosphere of self directed, self paced and flexible learning within a framework of desired outcomes.

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THE PRACTICAL LEARNING EXPERIENCE AT FIRST YEAR LEVEL

As has been noted [3] it is beneficial for students to be involved in "hands on" tasks across their entire degree program, as such, all engineering students at UoW are required to enrol in the first year course: Foundations of Engineering. It is in this course that they begin, or continue, their foray into experiential learning.

Many freshman science and engineering courses involve some aspect of practical or laboratory work, where students gain skills and experience from hands on activities; however, the majority of them are presented as a set of experiments, with predetermined outcomes and only incorporate group work as a means of reducing resource usage. Since its inception, the Foundations of Engineering course has included a design/build/test project as the main feature in the laboratory course. The premise being that this type of activity is an effective tool to reinforce aspects of: the engineering design process, working within constraints and creative problem solving [5]. Additionally, it is hoped, the implementation fosters effective teaming skills.

In its current iteration this project sees student groups (syndicates) designing, building and testing radio controlled model speed boats. The syndicates contain between five and eight members and are arbitrarily assigned. Each syndicate also has a final year engineering student as a project manager. The inclusion of the project manager serves a dual purpose: the final year students require project management experience as part of their qualification [6] (a skill that is difficult to develop when it is taught solely through lectures); the first year students gain the expertise and experience of a senior student, who fills the leadership role from the outset of the project. The project brief is reasonably open, though not so broad that students are left floundering unable to locate a starting point. The brief amounts to a single A4 page and covers boat specifications such as maximum dimensions, water tightness, safety considerations, resource constraints including materials limitations, budget, construction time allowed and laboratory conduct involving health and safety, the project manager's role and penalties for breaching the rules.

The project has not totally eliminated the use of set experiments, there is still a set of six activities that are used to emphasise aspects of boat performance and construction that should be taken into account during the design process. This set of activities also allows a period of "soak" time where the syndicates can start coming together as a coherent unit and begin designing their boat.

The design of the boat is up to the syndicate, working within the scope of the project brief, and in the past has resulted in a wide variety of designs. This was due to only maximum dimensions being specified, with no restriction placed on hull type, and the budget for motors being the only restriction. This flexibility allows the students to explore creative solutions to the design problem posed to them.

Building of the boats is limited to five 3 hour laboratory sessions, where students can only use the tools and materials made available to them, this way no syndicate can gain an advantage through syndicate members have greater resources available to them personally. The building of the boats is carried out under the supervision of appropriate staff to ensure that: health and safety requirements are met; students can receive constructive feedback on their design implementation.

The final aspect of the project is a race day, held on the last day of semester. An effort is made to turn this race series into a finale for the course, with marquees and sound systems hired, and the engineering student association hosting a barbecue. As well as acting as a social event, the race series allows the boats to be tested and assessed based on their performance.

Assessment

There are three main aspects that count towards the assessment of this design/build/test project:

- A step by step design processes. Where students describe the concepts and decisions that lead to their final design
- The boat itself. How well did it perform? What care and attention has gone into building the boat? Has there been novel or innovative use of materials?
- A performance appraisal. Three things need to be appraised: the boat, the syndicate, the project manager. This allows the students to reflect on how effective their efforts have been and also provide feed back to the syndicate manager, so that they can gauge and improve their role.

Outcomes

Anecdotally, the students enjoy designing and racing model boats. While this may seem trivial, students who enjoy an activity are much more likely to engage in the learning process associated with it [7]. This engagement leads to a number of outcomes, some of which the students do not appreciate until after they have graduated.

While there will have been some "hard" practical skills developed during the construction of the boats, it is believed that the "soft" skills that develop are of far greater importance and more transferable:

- First hand experience of a design/build/test activity similar to what many engineers face as part of their employment, a flexible learning opportunity; and realisation that sometimes things do not go to plan and problems need to be solved.
- Experience of having to work within constraints, be they available materials, time or money, and come up with creative solutions to overcome or minimise these restrictions.
- Improved interpersonal skills from having been in a team of (initially) unfamiliar people, whom they have had to bond and work productively with.

Developing these soft skills early in their university career allows students to implement and refine them in larger projects, in later years of university study, and also during industry work placements.

INDUSTRY PLACEMENTS

Work placements are an important part of engineering students' education at UoW. They allow students to learn technical and personal skills and gain practical experience and insight into workplace culture that they would not have the opportunity to gain at the University [8]. The partnership between University and workplace in educating students is commonly called Cooperative Education [9, 10].

Around 200 BSc (Tech) and BE students in the School of Science and Engineering are found paid work placements every year by the Cooperative Education Unit. The Cooperative Education Unit consists of six part-time and full-time placement coordinators from a range of science and engineering disciplines. The BSc(Tech) program has been running for 20 years, but the BE program was only recently established and has rapidly increased in popularity, with over half of placement students enrolled in a BE in 2007. Each student completes approximately 800 hours work experience over two placements at the end of their second and third year.

The placement process at UoW is different to other Cooperative Education degrees in New Zealand and around the world, in that the placement coordinators are responsible for finding the work placements for students [11]. Similar programs at other universities require students to find their own placements, a difficult task given that a student has limited practical and work place experience.

The placement process typically consists of regular meetings between placement coordinators and students throughout the year to determine placement preferences; give career, CV and cover letter advice, to provide interview practice, and notify students of placement opportunities. The Cooperative Education Unit has a pool of 200 employers from a broad range of engineering and scientific disciplines that it works with each year.

Placement coordinators approach employers and match potential students to placements based on the student's area of study and demeanor. Employers are then sent CVs and interview students. Once students have obtained placements, they are assigned academic supervisors who provide technical and report advice.

Typically placements are between November and February, but occasionally a student may do a full year placement overseas or in New Zealand. Once on placement students are asked to set themselves learning objectives of, for example, specific technical or interpersonal skills or knowledge they wish to develop or gain in-depth understanding of. They discuss their objectives with the employer, academic supervisor and placement coordinator, who then help the student refine their objectives and map out methods by which they can achieve their goals.

While on placement, placement coordinators visit the students and their employers to ensure the placement is running smoothly and the student is performing satisfactorily.

Students complete a 30-40 page report on their placement in which they describe their learning objectives, their company, the work done, results found, conclusions and reflection and review. The reflection and review encourages students to think about what they gained from their placement in terms of technical skills and personal development, understanding of workplace culture, how the placement impacted on career choice and how they met their learning objectives. Student reports are edited and marked by the academic supervisors and the employers, the University and students retain a copy.

Once the placement is completed, employers are sent a student evaluation by which they grade the student's performance. This contributes to the student's final placement grade. Generally most employers are very pleased with student performance.

The work placement program at UoW has been very successful with employers returning each year for more students. Most students finish their degree with an employment offer from their placement or have very quickly obtained fulltime employment. Furthermore, it is believed that their experience in an industry environment develops the maturity students need to undertake more in depth projects such as Formula SAE or the NZeco project in the latter stages of their degree.

FORMULA SAE

The Formula SAE (FSAE) competition has been running annually for over 20 years. In this competition, conducted by the Society of Automotive Engineers, students are presented with a hypothetical situation, whereby the have been engaged to design, fabricate and demonstrate a vehicle for the "nonprofessional weekend autocross racer". Furthermore, they must show that four cars can be produced per day at a cost of no more than $25,000 [12].

Each of these cars competes in a series of static and dynamic test events where they score points. These events and their allocated score are as shown in Table 1.

TABLE 1: FORMULA SAE SCORING

Static Events	Dynamic Events
Presentation 75	Acceleration 75
Engineering Design 150	Skid-Pad 50
Cost Analysis 100	Autocross 150
Competition Total: 1000	Endurance 350
	Fuel Economy 50

Although the competition has been conducted for in excess of 20 years in the USA, with over 100 universities competing annually, a separate competition has only been held in Australasia (FSAE-A) since 2000.

In 2005, the FSAE car concept was introduced to UoW students as an option for their major design exercise in their second year engineering design course. Approximately half the students in the class elected to undertake this exercise, working in groups of 4-6. From their experience designing a car in their second year, approximately 25 of the students, mainly mechanical and electronic engineering, decided to build a car for the FSAE-A competition during their third year of study, in addition to their regular course work.

Before building the car the students developed an organizational structure for their team based on what they saw as the necessary elements of an engineering organization undertaking such a task. The organizational structure is shown in Figure 1, with the team having an academic advisor, as mandated by FSAE rules, as well as a postgraduate mentor who had been involved in the FSAE-A competition in previous years.

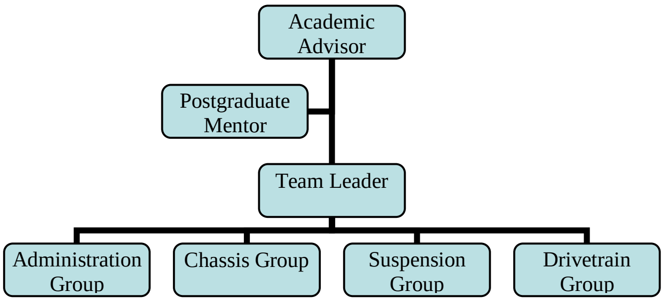

FIGURE 1: FSAE-A TEAM STRUCTURE

Although the organizational structure reached by the students appears to be a rigid hierarchical one, a very "hands off" approach was taken by the academic mentor. The aim of this was to allow students enough autonomy to explore creative solutions while still allowing a necessary degree of managerial and financial control. For the most part, it was found that students responded well to this arrangement with very little technical support being needed to be provided by the academic advisor.

Furthermore, it was found that in addition to the "formal" structure that students began to recognize the informal relationships that existed between the sub-groups. Some common examples included the interfacing of the engine and the chassis and also the suspension and drivetrain. Although not specified on the organizational chart, the students growing understanding of these issues and their ability to work in this environment showed a developing understanding of project management and engineering in a "real world" environment.

Because a "hands off" approach was taken by the academic advisor, it fell upon students to determine the methods they would utilize in designing and developing their car. As the students were initially inexperienced, they utilized the design techniques and strategies they were familiar with, a common approach in the development of expertise. In essence this revolved heavily around the use CAD and some FEM analysis in initial developments.

With the ongoing development of their car, students became more proficient in their use of computer aided engineering (CAE) principles. Furthermore, with time, the students began to utilize techniques that they were being taught concurrently to develop the car further. In particular, the use of mathematical modeling for designing and analyzing the compulsory impact attenuator to be fitted to the car highlighted this.

The fact that the FSAE car was developed outside the usual coursework channels meant that feedback to the students was far more challenging. Whereas a student undertaking a prescribed program could expect feedback through the standard assessment channels, feedback for the FSAE project was provided by comparatively informal means. At a managerial level, the team leader would receive briefings from the academic advisor with regard to the provision of funding and the communication of university policy and position on the project. At a technical and operational level, the students were provided with feedback both by the academic advisor and their postgraduate mentor. In addition to these feedback mechanisms, it was found that students began to develop their own "peer review" systems whereby designs would be examined before going into manufacture.

Ultimately, however the greatest feedback was provided by the competition itself. In essence this allowed students to benchmark their performance, not only against their classmates, but against students from other universities. In their first year competing in the FSAE-A competition, UoW came 19th of 27 teams and was the highest ranking first year team. Based on this result, UoW aims to further their involvement by completing a car for the 2007 FSAE-A competition.

Finally, a large number of team members from the 2006 car, are returning to work on the development of the 2007 car. It is hoped that the experience gained by these students will allow them to undertake an informal mentor role to aid the students from earlier years of the degree program. If successful, this may result in students developing a much better understanding of "real world" engineering before they undertake projects such as NZeco, or graduate and begin working as an engineer.

NZECO PROJECT

As with the Formula SAE car another interdisciplinary team of students is working on the two year, NZeco electric car project to be completed in October 2007. The NZeco car is a two seat electric sports coupe aimed at demonstrating the potential of long range, high performance battery cars. Once completed, a team of students aim to demonstrate the car in the World Solar Challenge (WSC) in Australia. The car will be driven 3000km from Darwin to Adelaide only on battery energy, stopping each evening to recharge its Li-ion battery packs. A computer model of the car created by students is shown in Figure 2.

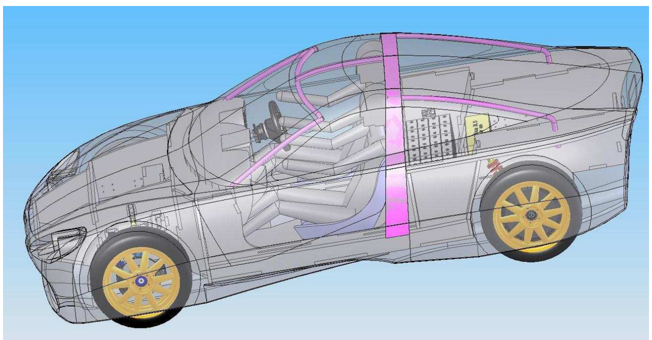

FIGURE 2: NZECO CAD MODEL

In 2007, the NZeco project comprises a team of 5 final year undergraduate engineering students, 2 graduate engineering students, 2 academic supervisors, 1 independent assessor and 3 mentoring engineers from a partner company.
The learning experience of the students covers a range of subject areas, from research, design and application of

engineering principles to team work and project management. Given the scope of the task, the NZeco project adopts principles of team project and problem based learning (PBL) strategies, practiced by many university teams developing vehicles for the WSC. The educational areas covered by these strategies are shown in context of the project in Figure 3.

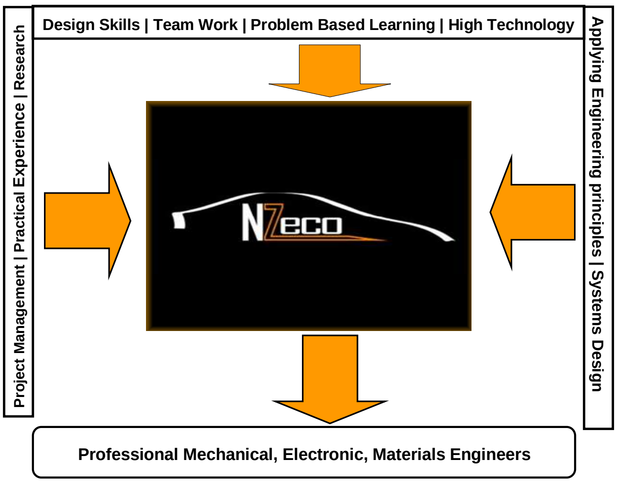

FIGURE 3: NZECO PROJECT STRATEGY

The requirements for the learning environment and advantages of project and problem based learning methods have been widely discussed, for example [13-18]. As the NZeco project relies not only on students, but on complex inter-relations between students, university and industry, there are a number of key practical issues required by the NZeco project to maximize the probability of its success for both student learning and the project as a whole.

Before embarking on such team based, engineering design and build projects, there are several important project and organizational issues that need to be addressed by supervisors and department managers to help facilitate a successful project outcome:

Objectives - The team must have clear overall objectives so that all students, supervisors, mentors and assessors understand what they must achieve and by when. Details are not necessary at this stage, as they are determined by the student team during project planning. However focusing the team on a clear and required outcome is essential

Learning Environment – For the NZeco project there are no formal lectures for the students involved with the project. Supervisors and students sit around a cleared table (mobile phones off) and after a formal project meeting lasting approximately 30 minutes, group discussions are encouraged covering any area of the project. To aid communication, a white board with a facility for hard copy print-out is sited in the meeting area. Also, a computer system is available for displaying 3D CAD models and real time changes made if deemed beneficial.

All team members are encouraged to contribute ideas to problem solving and an atmosphere of open mindedness is actively fostered to encourage free flowing thinking and to ensure the "quieter" students get the opportunity to contribute. It has been found that if supervisors leave the discussion after some time, the students continue developing often high quality solutions. It should be noted that it is important that the supervisors do not dominate the meetings or discussions. However, supervisors and mentors can and should act as knowledge bases for the students as it is normal for undergraduates to lack the knowledge accrued only from years of professional practice.

Assessment - The student work on the project forms a major part of their overall assessment – at UoW the project accounts for 50% of the final year mark and is divided into three areas: management (10%), research (30%) and design (60%). The high allocation of marks ensures students commit themselves fully and appreciate that poor project performance will lead to low degree classification.

Fairness - Assessment must be seen to be fair and balanced. This is achieved at UoW by supervisors attending all project meetings and a team of 3 assessors (including the 2 supervisors) reading project reports, interviewing and finally grading each student. This ensures supervisors are aware of the activities and progress of all students on the project. Regular meetings give the opportunity of feedback especially to students who might be under performing, enabling them to remedy the situation

An end of project interview gives each student the opportunity to demonstrate their work and explain what they achieved to each assessor. Each interview takes approximately 20 minutes and is worth 25% of the overall project mark.

The marks allocated by each assessor are not discussed until a grading meeting at the end of the project. As well as assessors grades there are mentors comments that are considered when there are major discrepancies between assessor's grades. Anecdotal feedback from students in 2006 indicated that they we very satisfied with this assessment method.

From the progress made to date by the students, it has been observed that students enjoy the flexibility that they are offered in the NZeco project. Furthermore, it is apparent that the students have matured professionally through their involvement with the project.

It is believed that the mix of a supportive but flexible learning environment, coupled with a structure of academic rigor and assessment has helped develop this in the students. Furthermore, the ability of the students to complete the undertaking will further serve as an indication of the soundness of such a learning environment.

DISCUSSION

From the experience at UOW, it has been found that there are a number of key points that need to be observed in offering flexible student learning opportunities. Aside from the academic objectives such as the provision of objectives and goals, and the nature of assessment, there is also a need to observe "obvious" requirements of this teaching strategy, in particular:

Commitment – Firstly there must be a commitment from the department to support the project financially and physically.

Supervisors must be fully committed to the project and should where possible match that of the students. This requires high levels of staff visibility and access. Projects of this type have many potential "road blocks" that hinder progress and must be resolved quickly. Typical issues include student access to workshops, disputes between team members, problems with technical support staff, obtaining advice on key decisions and resource allocation. Without supervisor assistance anyone of the aforementioned issues can lead to project failure.

Responsibility - Students must be given project management responsibility. Students should be strongly encouraged to elect a project manager who chairs each meeting with another team member acting as secretary to take minutes. The team manager should liaise with supervisors to resolve issues that are beyond their control. For a team to succeed, at UoW, it is considered essential that the students 'own' the project as this from past experience has ensured greater commitment from students.

Resources - Appropriate resources should be made available for the project, including: project space, workshop access, finances, technical/computer support and purchasing mechanisms. This is particularly pertinent to larger projects, such as the Formula SAE or NZeco project mentioned. In such projects it is not always possible to have all resources available at the start of the project, one requirement of these student teams is the development of a sponsorship plan to attract both financial and "in kind" support from industry. Experience has found that if properly conducted this activity can generate at least 50% of the required funding and materials, in the case of the NZeco project over $200k was raised this way. This activity also exposes students to other issues such as marketing and communication and is considered an important learning activity.

Flexibility – From experience, projects of this nature never run smoothly. There are always numerous unforeseen issues that hamper and disrupt the original plan. A flexible approach is therefore considered essential for a successful outcome. Flexibility can mean reducing expected outcomes when resources fail to meet those required or increasing them if an opportunity arises to do so. A flexible attitude should be promoted throughout all team members and changes should be looked upon as "yet another" problem solving activity.

Though difficult to organize, resource and manage, projects such as those discussed in this paper are considered to be an invaluable learning tool at UoW. Students have commented that compared to conventional lecture based learning, the projects are far superior in developing skills such as problem solving, team work, practical experience and project management.

Given the early stage of Engineering at UoW, and the apparent success to date, it is hoped that the provision of a flexible approach to learning, through the use of practical project based learning tasks, integrated with a commitment to maintaining academic standards, will form a model for engineering education, both locally and more widely in the future.

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