AC 2009-424: PREPARING BETTER ENGINEERS: COMPULSORY UNDERGRADUATE RESEARCH PROJECTS THAT BENEFIT UNIVERSITIES AND THE PROFESSION

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Preparing Better Engineers: Compulsory Undergraduate Research Projects that Benefit Universities and the Profession

Abstract

Engineers are responsible for creative, innovative and adaptive designs that solve challenging technical problems and provide sustainable solutions. Professional skills (i.e. management, social/cultural appreciation, budgeting, communication and personal development) are recognised by the profession as an integral part of an engineer's formal education. However, most engineering programmes do not specifically teach these skill sets. We recognised the need to better prepare students for real-world engineering practice that demands innovation and professional skills as well as technical competence. We therefore developed a successful model in which engineering students integrated technical information and professional skills through a real-world research project established in partnership with industry. Material taught throughout a four-year curriculum culminated in the compulsory (equivalent to ~8 credit hours) assessed research project that acts as a pathway towards real-world and sustainable engineering practice. A uniqueness of our model included indigenous people's cultural engagement, where students were taught the importance of understanding and working with indigenous peoples for successful engineering outcomes. The final year student research project benefited the university, students, industry, and the engineering profession at different levels through financial and other gains. The University and its students acquired industry funding, sponsorship, scholarships, graduate employment and research partnerships. Industry and the profession profited from better prepared engineering students, early recruitment opportunities, company marketing and cost-effective tax-deductible research partnerships. To successfully implement compulsory undergraduate research projects, support from colleagues and the profession is necessary. While financial and personnel resources are limited in times of economic uncertainty, we have mitigated these limitations by partnering with external mentors.

Introduction

Engineering employs mathematical and creative applications of scientific principles to solve problems and design solutions for the benefit of humans and their environment. While most engineering students comprehend the theoretical principles of technical tasks, they struggle with evaluating and synthesising real engineering problems due to a lack of actual experience[1,2]. Such experience can be gained through real-world engineering research projects, where creative and adaptive problem-solving is facilitated in a contextual learning environment[3,4]. Contextual learning is especially important for natural resources, environmental, biological, civil and other engineers who practice at the interface of the living environment (i.e. ecosystems)[5].

Industry depends on its ability to attract graduates with a deep technical and broad professional skills base. Professional skills are considered an integral part of an engineers formal education as stipulated in the professional guidelines provided by the U.S. Accreditation Board for Engineering and Technology (ABET) and the Institution of Professional Engineers New Zealand (IPENZ). Six professional skills defined by ABET in their accreditation criteria are[6] :

- an ability to function on multi-disciplinary teams;
- an understanding of professional and ethical responsibility;
- an ability to communicate effectively;
- acquire the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context;
- recognition of the need for, and an ability to engage in life-long learning and;
- knowledge of contemporary issues.

Similarly, recent accreditation guidelines for undergraduate engineering degrees in New Zealand define essential professional skills including[7]:

- the capacity to work in a multi-disciplinary and team work professional environment;
- appreciate the profession in terms of ethics and contribution within society;
- is able to communicate effectively both written and orally as well as interact effectively with others;
- appreciates the commercial and legal environment;
- understands the relationship between engineering and society;
- appreciates and has sympathy with other value systems/perspective as well as the long term goal of society;
- is situation, not technique focussed and takes into account all relevant factors in their work and;
- appreciates the work environment in a cultural context.

These professional skills have become a critical concern for current societies and so should be an integral part of all engineering curricula to better prepare graduates for the profession. A well structured curriculum where the first, second, and third years support a final year capstone design experience enables students to acquire these important professional skills[8]. Changes in the fragile world economy, student and professional mobility, advanced communication technology and increasingly loud voice of the social imperative, have all influenced engineering practice and necessitate the acquisition of skills beyond technical competence alone[9].

It is well reported that real-world projects serve as a nexus between engineering theory and practice[1,4,8] and so our aim was to advance students' competence for engineering practice. We hypothesised that by empowering students to integrate material learnt across their courses in the form of a real-world engineering project, they become more engaged with the reality, expectations, critical thinking, creative and professional skills required for competent professional engineering. Recent research in engineering education has also emphasised the importance of involving industry in engineering curricula design, including project sponsorship[4].

This paper outlines a successful model of a compulsory final year research project in an undergraduate (honours) Natural Resources Engineering degree. The project aims to develop and enhance students' professional skills, as well as providing the opportunity to engage in real-world research with industry. Material taught in a four year curriculum culminates in a research project that acts as a pathway towards actual engineering practice. This paper also shows how these projects provide a wealth of additional (including financial) benefits to both the university and industry and fosters longer-term community service learning.

Natural Resources Engineering Degree

Since its inception at the University of Canterbury in 1967, the Natural Resources (formerly Agricultural) Engineering degree, for which we refined the research project, has been accredited by the Institution of Professional Engineers New Zealand (IPENZ) and is internationally recognised through the Washington Accord. The degree has evolved to teaching wise use of the natural resources; water; soil; ores; wind and; wastes as well as mitigating ecological impacts from technological developments harnessing these resources[10,11]. It is somewhat unique, although closely related to international programmes in biological[12,13], biosystems, bioresources[14], ecological and agricultural engineering[16,17,18]. Graduates of the programme primarily work in urban and rural aspects of water, waste and land engineering and management, such as river engineering, irrigation design, erosion control, ecological stormwater management, contaminated site remediation and wastewater treatment. Therefore, the focus of the degree is conducive to partnering with environmental protection agencies and local industry in solving complex and real-world engineering challenges.

Development and Structure of the Final Year Research Project

Our involvement in leading the Natural Resources Engineering programme commenced in 2004 and so we report mainly on relevant outcomes achieved since then. Each student was expected to spend approximately ten hours a week on their project (Table 1). Up until 2006, two term individual research projects (equivalent to 3-5 credit hours in the USA Engineering system) were mandatory for all final year students in the programme. Thereafter, projects became four term long individual projects with an equivalent of 6-10 USA credit hours. Increasing student enrolments coupled with resource (academic, technical and space) constraints enforced reviewing the way we facilitated these research projects without compromising their value to students. Simultaneously, projects evolved into more real-world partnerships with industry as a means towards better integrating students with the context of engineering practice. In 2007, student teams of three embarked on a four term group project while this was modified to teams of two in 2008 after we observed that teams of three were not ideal. The impetus for moving towards group projects was primarily due to a limitation of available academic supervisors but also to recognising the synergy derived from team efforts observed in other courses and the necessity for students to engage with a diverse work force upon graduating.

Table 1: Evolution of Final Year Research Project (ENNR 429) Format 2004-2009

Year	# students	# students/group	# terms*	Expected # hours on project per student
2004	8	1	2	120
2005	10	1	2	120
2006	7	1	4	240
2007	18	3	4	240
2008	16	2	4	240
2009	22	2	4	240

** The academic year (~ February 25th – October 17th) is divided into 4 terms.*

Most other engineering programmes in our College have compulsory final year projects, whose structures vary (Table 2). The Civil Engineering programme in our Department currently offers both two and four term individual projects for students with a higher GPA. In line with 2007 guidelines of the National Committee on University Academic Programmes (CUAP), which states that final year honours engineering students must engage in 25% research, our College of Engineering is requiring that all undergraduate programmes comprise a four-term project course, similar to the model developed for the Natural Resources Engineering degree.

Table 2: Project Structure in College of Engineering at the University of Canterbury (2008)

Degree	# students	# students /group	# terms	# hours expected on project per student
Electrical	80	1	4	240
Chemical and Process	38	1	2	120
Chemical and Process	10	1	4	240
Civil	12*	1	2	120
Civil	5*	1	4	240
Mechanical	127	4	2	240
Natural Resources	16	2	4	240

**17 out of 113 final year students enrolled in Civil Engineering in 2008 engaged in a project.*

Objectives and Learning Outcomes of the Project Course

Projects designed jointly by engineering academics and industry practitioners typically included a premise of sustainable engineering problem-solving where interdependencies between people, the environment and the economy were embedded in their technical solutions. There is a strong focus on sustainability in the Natural Resources Engineering degree and so the project course aimed to foster this ethos. The primary objective of the project was to provide students with an opportunity to work within teams in solving complex and real-world engineering challenges while developing their professional skills. The sequence of course objectives is given in Table 3.

Table 3: Sequence of Objectives of Final Year Research Project

Term	Objective
1	Develop detailed and quality assured methodology for conducting a rigorous (team-based) research project
1	Generate a detailed budget, timeline and project management strategy
1	Write and present a mini research proposal examined by programme academics
2,3	Generate, collate and critique data for a defined problem. Perform necessary statistical analyses/modelling
2,3,4	Design a sustainable solution for the defined problem incorporating triple-bottom line considerations (integrated ecological, economic and cultural facets)
3,4	Produce sound conclusions and a substantial literature review
4	Deliver final technical report, oral presentation and attractive poster

The associated learning outcomes from the project aimed to equip students with the skills necessary to:

- Contribute an original and practical solution to a Natural Resources Engineering problem;
- Apply creative, adaptive and effective solutions to defined engineering problems;
- Plan effectively and execute work, individually and as a team, within defined programme and budget restraints;
- Obtain insight into developing and managing effective research;
- Consult and liaise with various stakeholders involved in the engineering task;
- Communicate effectively in written and oral presentations;
- Appreciate and communicate the implications of engineering projects in relation to the principles of the Treaty of Waitangi (New Zealand cultural engagement).

Project Assessments and Workshops

Assessment by a team of academic supervisors of student project performance was based on demonstrated written technical and oral competence (Table 4). Although all assignments were team efforts, each team allocated specific tasks to its members, while marks individual students received were weighted according to confidential quantitative and qualitative peer feedback.

Table 4: Project Course Assessments and Associated Weighting

Assessed Item	% of total grade
Project Proposal and Presentation	10
Mid-year Report	20
Oral Presentation and Abstract	10
Final Written Report	50
Poster	10
Confidential Peer Assessment	---

Project proposal and presentation:

The project proposals (five page limit) are modelled on prescribed research proposals required from graduate students in our Department and include project aims and goals, milestones, human and material resources, timetable for completion and expected outcomes or results. Each team is also allocated ten minutes to present their research proposal orally within three weeks of the start of the course. Academic supervisors are heavily involved at this stage and students are advised to become efficient yet effective at engaging with those involved with their research (industry partners, technicians, supervisors, etc.). This process requires them to use and develop their professional (especially interpersonal and management) skills from the start as well as knowledge skills in deriving appropriate methodologies. The proposal is also an important component in the initial step towards understanding research scopes within time and budget constraints.

Mid-year report:

The Mid-year report structure adheres to that of the Final report, which includes; a detailed literature review; appropriate theoretical or experimental background; and methodology for work already conducted as well as remaining work. This enables students to develop their technical writing, literature retrieval and knowledge critiquing skills as well as critical planning and time management skills. A budget and timeframe for completed and uncompleted work is appended to all progress reports. If students are found to be struggling with progress on the project, its direction, robustness or management, supervisors have a chance to intervene earlier and direct the students towards solving the problem efficiently akin to an apprentice mentoring role.

Final report:

Students are graded on their 'Draft' Final report (as submitted) but are required to integrate the feedback and corrections provided by the academic assessors before receiving their grades. By this stage, students have usually significantly improved their technical writing and time management skills as well as grasped a clearer understanding of research applications. They also have engaged in a partnership with the engineering profession.

Oral presentation:

A 15-minutes oral presentation (plus 5 minutes question and answer session) is given to an audience of academic, technical and industry personnel. Presentation skills based on technical content, coherent delivery of information, ability to engage audience, competence in answering questions and level of knowledge articulated are quantitatively assessed.

Poster:

In order to produce an A1 size poster, students receive instruction in CorelDraw, a software package made available to all students with hands-on support from a graphics technician. Posters are assessed on clarity, uniqueness, simplicity and visual attraction rather than depth of knowledge, thus aiming to facilitate student's creative and communication skills. These posters are typically displayed throughout the Department to promote the various research successes.

Confidential peer assessment:

Students are given the opportunity to evaluate their group member's performance twice during the project course (at the start of term 2 and end of term 4). Evaluations are used to ensure that there is an equal contribution from team members and provide students (and faculty) with some recourse for raising concerns in a formal manner, where applicable.

Feedback:

Detailed and constructive feedback on all assessments is provided to students both orally and in written form by at least two academic supervisors. One serves as the supervisor of the project, while another serves as a supervisor for one of the other student projects. Typically, the principal project supervisor provides additional feedback on a weekly basis during regular meetings and sometimes additionally by email, as required. This process ensures that students are provided with iterative and timely feedback offering more constructive learning than normally afforded.

We also developed non-assessed but compulsory taught workshops listed in Table 5 in order to better equip students with further professional skills required in engineering practice. The Treaty of Waitangi is New Zealand's broad statement of principles on which the British Crown and native Maori signed a political pact in 1840 to build a New Zealand government. Since Maori are the legally and culturally recognised guardians of New Zealand's natural resources, it is imperative that practising engineers understand, communicate and work under the premise of the Treaty. Students attended two full-day interactive workshops facilitated by a non-for-profit organisation to learn of the principles and implications of the Treaty.

Table 5. Non-Assessed Compulsory Taught Workshops in Project Course

Instruction	**Delivered (term of academic year)**
Treaty of Waitangi cultural workshop (two full days)	Term 1
Library skills using Endnote referencing system	Term 1
Preparation of a research proposal and budget	Term 1
Written and oral communication skills	Terms 2 and 3
Poster creation skills using CorelDraw software	Term 3

Although students receive continuous feedback from supervisors directly on their research progress, technical report writing is taught in a written communications tutorial, while an oral communication skills session covers best use of standard software packages (i.e. PowerPoint) as presentation tools. Students are provided with the Virtual-i Presenter software programme[19] to help them practice their oral presentations. This software allows students to record presentations with a webcam, review them and solicit constructive feedback from others on their performance.

Results and Discussion

Student assignment grades, course GPAs, industry partnerships fostered and evaluating where students' professional skills were developed in our course components, helped assess the success of our project course model. We report on these outcomes through a number of categories as:

- Project diversity and selection
- Individual student GPA in project course compared to their overall GPA
- Gender differences
- Professional skill sets developed in course components
- Research and teaching partnerships developed with industry

Project diversity and selection:

The variety of the research projects over the years has been wide reflecting the nature of the Natural Resources Engineering programme. Many projects were concerned with finding more sustainable solutions to managing urban stormwater, municipal wastes, land erosion and sediment transport, energy efficiency in buildings and river engineering. Usually projects were prescribed by supervisors and chosen by students, while many projects were integrated into the community making them service learning challenges. Furthermore, most projects were funded by industry partners and thus, the University incurred little or no research costs. Anecdotal feedback from students indicated that most were inspired in their project selection by a particular pre-requisite course (and/or associated faculty member). Usually, students demonstrated a strong aptitude in the research discipline of their project indicating that they perform better in topics with which they enjoy. We are unsure how students chose their team mate(s) as some of the group members had very different aptitudes, work styles and attitudes. We speculated that students primarily chose the topic of interest, which was confirmed when we were required to assign a number of students to groups when they had chosen a project but not their research partner(s).

Individual student GPA in project course compared to their overall GPA:

Individual student grades for the project course from 2005 to 2008 (n=49) were on average slightly greater (5.44 out of 9.0) than their overall GPA (5.29 out of 9.0) with a standard deviation of 1.57 and 1.46, respectively. A slightly higher GPA in the project course may have reflected the degree of constructive and iterative feedback from academic and industry mentors, which enhanced student learning. Additionally, students primarily chose the project they engaged in and were ultimately interested in its focus so exhibited a higher level of ownership and motivation. There was a 75% (Pearson) correlation between overall student GPA and the grade they received in the project course indicating that generally students' aptitude in research projects was closely aligned to their overall academic ability. T tests between overall student GPA and project final grades showed there is no significant difference between the two ($p>0.05$).

Gender differences in GPA:

We found that females (37% of the class cohort) had an average GPA of 6.36 (out of 9.0) compared to an average GPA of 5.13 (out of 9.0) for males in the project course. While we have no conclusive evidence for this significant disparity in grades, we speculate that females were quite focussed, often driven and frequently demonstrated greater conscientiousness in their work. Additionally, their effective communication skills and ability to work (and often lead) a team probably provided a better platform for them to achieve well in the project course.

Professional skill developed in course components:

We have attempted to match where specific professional skills (as identified by the engineering professional bodies) and personal development skills were met in the project course (Table 6). Specifically, we aimed to align course assessments to develop and assess these skills. By empowering students to develop these essential skills not always fostered in other courses, we found that students simultaneously became confident individuals demonstrating pride in their project achievements. Since industry depends on its ability to attract graduates with a deep technical and broad professional skills base, we believe that nurturing the development of these "softer" professional skills is as important as the technical competence they achieve throughout their degree in better preparing them for engineering practice.

Table 6: Skills Students Developed During Industry Partnered Undergraduate Research Projects

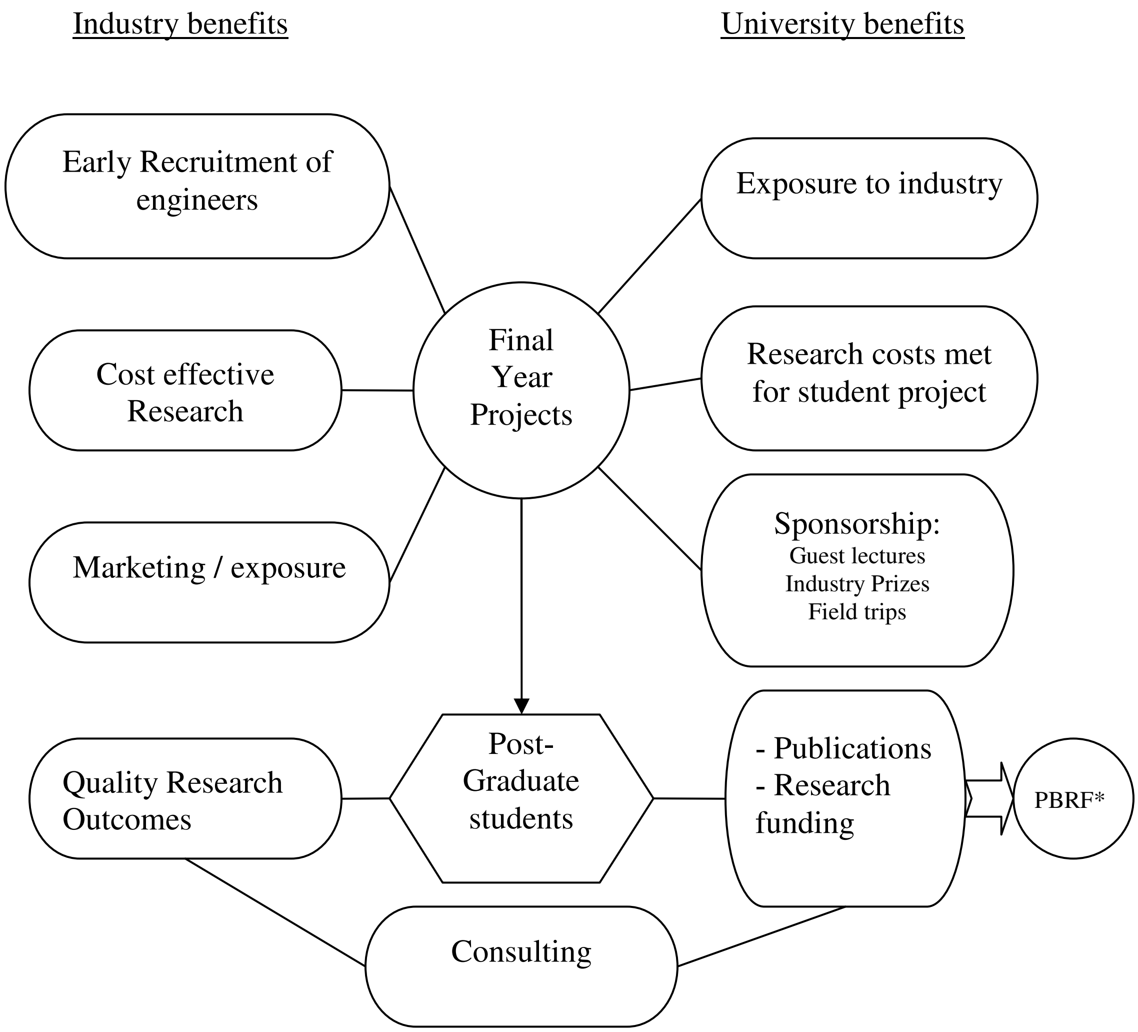
Skill Category	Skill Type	Method in which skill was developed
Technical	Insight into research and research skills	Hands-on research
	Technical design and trouble-shooting	
	Real-world problem-solving	Real-world project
	Communication (written, oral, poster)	Course assignments
	Professional apprenticeship	Partnership with industry
Social/Cultural	Human interpersonal skills	Partnership with industry
	Team work	Group assignments
	Ethical awareness	Waitangi workshop
	Cultural appreciation in engineering	Real-world project
Management	Communication skills	Course assignments
	Contextual legislation boundaries	Real-world application
	Time management	Course duration
	Project budgeting	Course assignments
Personal Development	Confidence	Project direction, responsibility, ownership
	Creativity	
	Patience	Research realities

Research and teaching partnerships developed with industry:

Our undergraduate research project model has generated a wealth of additional benefits to the university and engineering profession (Figure 1). Industry benefits by directly interacting with students, providing company exposure and affording early recruitment. They also benefit from academic partnerships and cost-effective research not easily afforded independently. Simultaneously, the University and students benefit from practical experience and financial support from industry in terms of guest lectures, course prizes, scholarships and field trips. Since the final year projects are research focussed, they often lead onto funded (post)graduate research activity fostering further collaboration between industry and the university. The university benefits moreover through increasing publication outputs, which lead to an overall increase in a PBRF (Performance Based Research Funding) score - a New Zealand government policy that distributes funding to universities based on measured research performance.

Conclusions and Recommendations

The compulsory research project model we developed in partnership with industry provides instruction to better prepare students for the complex challenges they will encounter in their engineering career. In particular, essential professional skills are fostered in a contextual learning environment, building on a comprehensive technical curriculum. These project partnerships also facilitated and nurtured a wealth of benefits to both university and the engineering profession and fostered longer-term community service learning.



*PBRF: Performance based research funding (New Zealand government initiative to distribute funding to universities based on research performance.)

Figure 1. Benefits to university and industry from Final Year Engineering Research Projects

While teaching aims to develop and enhance abilities and some professional skills, research entails learning by discovery with the primary goal of advancing knowledge and applied "know-how" [3]. We found that involving senior undergraduate students with a practical research project enhanced their understanding of research responsibilities and paved an opportunity to engage with research at a graduate level as reported elsewhere [20]. This aligns with one of our University's key goals in attracting more (post)graduate students into engineering.

To successfully implement compulsory undergraduate research, support from colleagues and the profession is necessary. A willingness to step beyond formal instruction learning and endorsement to do so by the relevant degree accreditation body is essential for successful outcomes. While financial and personnel resources are limited in times of economic uncertainty, we have mitigated these limitations by partnering with external mentors and believe we are preparing better engineers for the profession.

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