Developing multi-discipline design skills in undergraduates

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Abstract

The importance of incorporating design skills in undergraduate engineering programs is widely recognized. Demonstrating that students have been imbued with those skills is however, often poorly done with design not being well developed throughout a degree program. The paper outlines the processes adopted at the University of Tasmania to develop design skills and how the attainment of those skills is evaluated. A case study involving the development and refinement of a new multi-disciplinary design unit Experimental Design and Analysis is provided as an example of how to achieve good design learning outcomes.

Introduction

Much discussion continues to occur around integrating design, and the teaching of design, into engineering programs. Dodd and Stonyer[1] describe engineering design *as "providing the integration of engineering theoretical knowledge, skills and practical elements of an engineering degree"*, while also recognizing that attributes such as teamwork and communication are desirable of incorporation. While the authors accept such a premise as valid for the final years of an engineering program, they feel that it does not apply to the first year of a program when students mostly lack those elements. In fact it could be argued that a lack of engineering theoretical knowledge might benefit rather than hinder as the potential engineers will not be burdened or blinkered by preconceptions based on engineering science. Also ideally design should cross discipline boundaries for any potential engineer to truly appreciate how design occurs in the real world.

It is interesting to note that Green[2] hypothesized that most Australian engineering courses focus too much on the acquisition of design knowledge (rules) and too little on creativity and problem formulation. He concluded that engineers compare unfavorably with industrial designers who place emphasis on creativity and problem formulation via the use of design studios. It seems that engineers are increasingly constrained in their creativity during their studies while industrial designers are free to explore.

Developing design skills in professional engineering programs allows students to learn via active engagement and group project work. Green and Bonollo[3] describe design methodology as a process that includes the *"study, principles, practices and procedures of design",* with a focus on the understanding of the design process. It could be argued that what is truly being taught is design methods, design processes and design methodology. Such content is not appropriate for a first year design unit where potential engineers should be introduced to generic design that spans disciplines and encourages creativity. The authors realized very early that they had little interest in product design or development and preferred to concentrate on the following sequence, which encourages creativity. Green and Bonollo[3] suggest similar phases for what they term "*engineering design*", these being *"Clarification. Conceptualization, Embodiment, Evaluation and Detailing".*

1. Identification of the design task.
2. The emergence of design concepts.
3. The collection of supporting design data.
4. Rationalizing to a single design and
5. Creating a final design.

The authors chose the path that would involve "self-teaching" the students the basics of design by engaging them in multi-discipline, group-based, design project work. Students would be exposed to team dynamics and learn via engagement that communication, creativity, interpersonal skills and the ability to analyze results as a team are equally important to the professional engineer as is technical knowledge[4].

Implementation a New Design Unit

The implementation and integration of new content into an engineering program can be very difficult, as academics are generally loath to surrender time and space to any intruders who enter their domain. The typical response to any suggestion of change is, *"but it is essential that students know my work to be good engineers".* The authors were provided with a unique opportunity when there was a general restructuring of the engineering degree program at the University of Tasmania. The Tasmanian degree provides general coverage of six engineering disciplines in the first three semesters (1.5 years) of the course, and students have the benefit of being able to defer selection of a specialization until after first semester of second year. The disciplines are:

- Civil Engineering
- Mechanical Engineering
- Mechatronics Engineering
- Electrical Power Engineering
- Electronics and Communications Engineering
- Computer Systems Engineering

Impetus for inclusion of this unit in the course arose from other sources with both Engineers Australia and the University of Tasmania stressing the need for graduates to develop a set of generic skills during their degree program. The attributes required by Engineers Australia formed a specific set of exemplars of the more general attributes desired by the University. The skills focussed on in the development of this unit were "Ability to understand problem identification, formulation and solution", "Ability to function effectively as an individual and in multi-disciplinary teams" and "Ability to solve problems with minimal guidance". All of these attributes could be incorporated via group-based design work.

Unit Description, Development and Refinement

The new unit "Experimental Design and Analysis" was first delivered in 2002 as a compulsory course for all engineering disciplines in first semester of second year. In 2003 refinements were made, based on both student feedback and reflections of the academic staff involved in the project. In 2004 further refinement of the school's programs entailed the unit being offered in first year, to provide students with an earlier insight into the application of multidisciplinary engineering design projects.

The project requires students to investigate the use of a load cell as an object counting device and then design and build the counter. Teams of students design, construct and calibrate a load cell through the phases of materials investigation and selection, programming, design, data collection, analysis and finally calibration and prototyping (Figure 1).

The formal part of unit delivery format consists of one hour lecture, one hour tutorial and three hours laboratory per week. Specific theory relating to the project (cantilever design, introduction to strain gauges) is covered early in the semester and the remaining lectures cover various aspects of experimental work. The exploration of topics is designed to provide students with the theory required to complete each stage of the project, from system and experimental design, data acquisition, probability and statistics relating to error analysis, data analysis and an introduction to instrumentation.

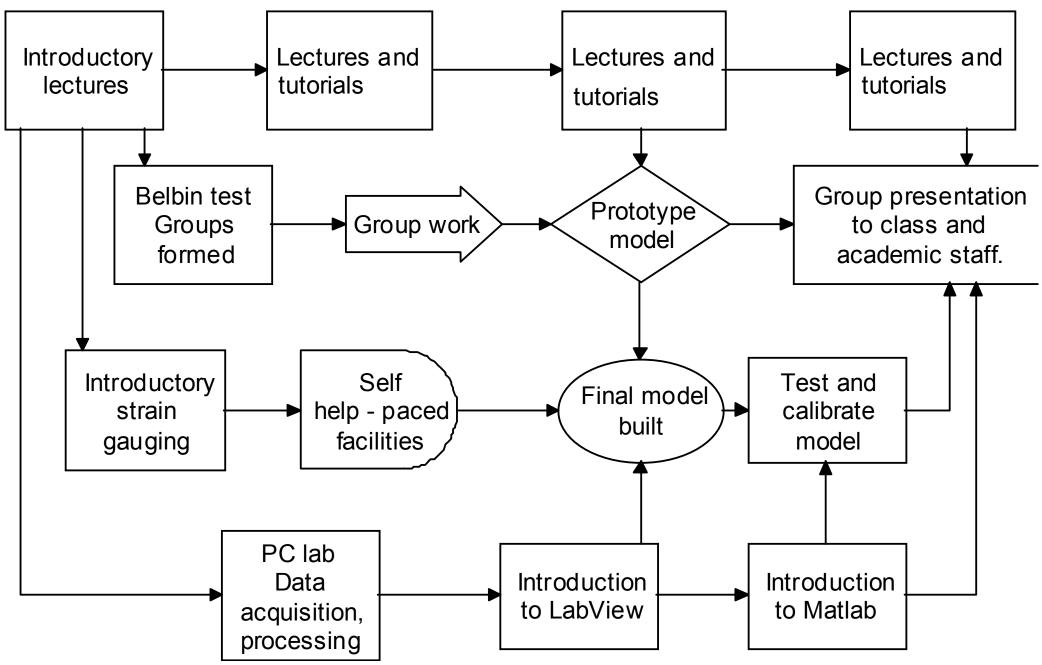

Figure 1: Parallel work streams in the unit

The emphasis in delivery of theory is on integrating the six engineering disciplines: power systems, electronics and communications, mechanical, mechatronic, civil and computer systems engineering. The laboratory time is divided between formal instruction in programming languages Labview and Matlab, which are required for the project; formal introductions to the project; formal instruction in the application of strain gauges; and, from 2003, formal workshops on group dynamics. The remainder of the laboratory time is allocated to group work for the project, and staff and laboratory space are available to student teams in a flexible manner. The number of students in the unit varies depending on intake but historically about 80 to 110 students would be expected to be enrolled each year.

The latest innovation in the unit is the incorporation of a large component of project-based learning and the assessment criteria. Small teams of four to five students are formed in the first week of lectures and team activities parallel the traditional lectures, tutorials and laboratory work. This approach of using project-based learning is an effective means of encouraging the development of and attitude towards life long learning skills [5,6].

The group project was intended to enhance and promote self-management, project planning and communication skills in the participating students. The unit content consolidated general engineering theory from units that students had previously covered. Student teams obtained data on materials, strain gauges and amplifier properties using their own investigation skills; carried out their preliminary work in dedicated laboratory space; completed analysis at their own pace and used the design process to integrate the project with academic teaching and instruction. The student teams were able to consult with technical and academic staff on a more informal and peer level basis. Staff operated less in an instructive mode and more as external consultant engineers, or facilitators to each group.

Ongoing Unit Refinement

To fully develop the students' understanding and appreciation of team work and group dynamics, it was necessary to include some explicit instruction and discussion of these issues within the course. Students are given material on group work in a formal session after the project had been initially defined. The Belbin test, which is a well-accepted means of classifying individual traits[7] is discussed in class, mainly with respect to how the test can be used to optimize team member selection. Each student completes the test individually and the selection of groups (by staff) is nominally random, but with attention given to distributing international students evenly amongst the groups. It was observed that the randomly selected teams appeared to be more focussed on their project work compared to clique groups.

In 2002 students formed their own teams. It was recommended that they form multidisciplinary groups, and use the team role concept to achieve a productive personality mix. However only two teams (out of 20) reported having attempted to form a multidisciplinary team. Students appeared to naturally form teams based on friendship groups, and international students were confined to their own groups. Students who were new to the course, or started after the first week found it difficult to join a group. This was not deemed to help students develop team work and lead to staff team selection.

The unit has been refined using reviews collected in the form of informal written comments from students and standard questionnaires (both formal University of Tasmania SETL [Student Evaluation of Teaching and Learning] forms and specific questionnaires developed by teaching staff). Outcomes from a review of the student assessment, feedback from staff involved in the project, and staff opinion of the student presentations and assessment were also considered[8]. The main areas for attention that have been refined are:

- The formation of student groups and member skills
- Balance of group versus individual assessment of students
- Integration of the subject with other units

As indicated earlier the importance of developing teamwork skills is discussed with teams in the context of generic attributes of graduates and examples of job advertisements and position descriptions. An overview of the stages of group formation, background to different personality types and learning styles is provided. After completing the Belbin test, and forming teams, students review the outcomes of the test with their group. Finally, the groups discuss and set out their objectives and ground rules by completing a team charter. This charter is used in reviewing the groups' progress in teamwork as well as the technical output during the semester.

Assessment

The merit of various methods of assessing students, particularly in units that aim to develop teamwork skills, has been the subject of much discussion during recent years [9]. Issues such as over-assessment, quality of assessment, equity and participation, web-based approaches and the balance between formative and summative assessment have been widely debated. The assessment for this unit is entirely based on coursework, a large proportion of which has been described as group work. A balance has been sought between individual and group assessment, so as to provide the required level of individual feedback, without detriment to the aims of the unit. In 2002 it was found that when marked against the criteria that had been set, the student assessment was higher than the distribution of grades generally considered being "acceptable" by the school and faculty. This is a typical outcome of units with a high proportion of group work, concentrated in a single project. In this case, it also reflected a large time commitment made by the students to the projects, particularly in the final weeks. However, it was decided that the balance of assessment should be shifted slightly back towards individual achievement, particularly focussing on evaluating independent performance of students.

The outline of student assessment handed out to students in the first week of lectures in each year, were as shown in Table 1. It was found that using the 2003 distribution, there was a good distribution of final student marks and that individual results accurately reflected their achievement in the subject.

Assessment Task	Mode	2002 weighting	2003 weighting
Tutorial	Individual	10 %	10 %
Test	Individual	10 %	20 %
Progress report	Group	10 %	5 %
Assignments	Individual	10 %	20 %
Design report	Group	50 %	30 %
Presentation	Group	10 %	10 %
Independent review	Individual	-	5 %
Total		30 % individual 70 % group	55 % individual 45 % group

Table 1: Student assessment task weighting

The assessment tasks are designed to direct the students to achieve the learning outcomes that have been set for the unit and to assess their performance in relation to the development of specific generic skills. The relationship between the learning outcomes, assessment tasks and the generic attributes is shown in Table 2.

Learning outcome	**Assessment Tasks**	**Generic Attributes**
Manage project development, teamwork and communicate project outcomes	Progress report, presentation, design report, independent project review	Ability to communicate effectively, not only with engineers but also with the community at large Ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member
Understand the processes of obtaining experimental data including the design of experiments and the use of basic instrumentation	Tutorial, test, presentation	Ability to apply knowledge of basic science and engineering fundamentals Ability to undertake problem identification, formulation and solution
Understand the limitations of measurements and apply this to expressing experimental uncertainty	Tutorial, test, presentation, design report	Ability to apply knowledge of basic science and engineering fundamentals
Assess the validity of hypotheses using experimental data and statistical analysis	Tutorials, test	Ability to apply knowledge of basic science and engineering fundamentals
Use and modify software tools to facilitate data acquisition and analysis.	Assignments, design report, presentation	Ability to apply knowledge of basic science and engineering fundamentals Ability to undertake problem identification, formulation and solution

Table 2: Relationship between learning outcomes, assessment tasks and generic attributes

Fitting into the Design Stream

The unit provides students with skills in error analysis, experimental design and data processing. The content has a general focus and should be able to be used by students to enhance the experimental laboratory programs in their other units. It was intended that the unit would draw heavily from Calculus and Applications and Engineering Mechanics and lead into Engineering Design and Project Management and similar units that have a design, experimental or laboratory component. The formal lectures focus on experimental uncertainty analysis and data analysis and are supported by tutorials that apply the techniques to sets of data that the students have measured in the laboratory component of the other subjects they are concurrently studying. This more clearly integrates the formal training in experimental analysis with the practical training they receive in the other units in their degree program.

In 2004 the unit became part of semester two Year One, to integrate it better into the design stream for all students. The design stream for the civil engineering specialization is shown in Table 3 and it is interesting to note that the students do not have much opportunity to be involved in creative and innovative design in third year. This stage of their design studies is devoted to learning specific design rules and processes. As an example for the civil engineers the unit Construction and Asset Management revisits Engineering Profession and Industry (a first year unit incorporating generic design of a large project). For example in 2003 the design project for the teams in Construction and Asset Management was to provide the overall conceptual and general design for a new yacht club, complete with environmental studies, moorings, architectural and all associated infrastructure. In 2004 first year multi-discipline teams design an intelligent building within the unit Engineering Profession and Industry.

Unit	Design Aspects	Creativity Opportunity
Engineering Profession and Industry (KNE121)	Multi-discipline teams conceptually design an “intelligent building”.	Very high. No hard engineering and imaginative solutions rewarded
Experimental Design and Analysis (KNE214)	Multi-discipline teams design a counter. Based on engineering science.	High. Innovation rewarded in design approach and creative presentations.
Engineering Design and Project Management (KNE211)	Cross discipline teams carry out specific designs that vary each year.	High. Designs are competitive, innovation and creativity rewarded.
Steel and Timber Structures (KNE315)	Civil disciple teams only. Engineering code based.	Low. Code based
Concrete Structures (KNE316)	Civil disciple teams only. Engineering code based.	Low. Code based
Civil Engineering Design 1 (KNE415)	Civil disciple teams only. Expands code work to encompass small projects	Medium as teams can produce innovative design but creativity is low.
Civil Engineering Design 2 (KNE417)	Civil disciple teams only. Expands code work to encompass large projects	Medium as teams can produce innovative design but creativity remains low.
Construction and Asset Management (KNE414)	Civil disciple teams only. Projects become multi-discipline.	High. Teams produce innovative designs and are rewarded for creativity.

Table 3: The civil engineering design stream

Project outcomes

The project-based unit enables students to develop their design/communication skills by learning in context. The group work encourages them to use flexibility in approach, generate dialogue and assist in their preparation for the real world of unstructured learning. Since the work is project-based there is a sharing of skills among the team members and development of the “team spirit” concept that is a very important aspect of professional engineering practice.

Students enjoy self-paced learning, within the general guidelines set by the school. Students are required to meet goals over the semester to ensure that individuals do not lag too far behind their peer group, and thus subject themselves to undue hardship and distress. Students have a more stimulating exploration of engineering principles and better resources for learning.

These outcomes are clearly demonstrated by the final student presentations where teams are given 10 minutes to demonstrate the operation of their load cell (the counter), and give a short presentation on the design, construction and calibration aspects. As teams achieve similar outcomes, they are encouraged to give innovative and creative presentations. The presentations demonstrated enthusiasm and included such special guests as a giant chicken, cricket team members, and television sales program host. Teams used video and theatrical skits as well as PowerPoint to deliver a series of entertaining presentations.

A student questionnaire was used to measure the effectiveness of this unit. Students completed the questionnaire in the week following the team presentations. The questions and results of the questionnaire for 2002 and 2003 are summarized in Table 4. One student commented on the questionnaire sheet, "while I was working on the project I suddenly realized that this was what Engineering was all about".

	Question	Responses in 2002 and ***2003***				
		SA	A	N	D	SD
1	Working on the load cell project helped me to understand the application of the theory taught in the course	23.5 ***25.6***	76.5 ***74.4***	0 ***0***	0 ***0***	0 ***0***
2	Working in a group allowed me to achieve a better result than I could have alone	23.5 ***24.2***	55.9 ***66.7***	17.6 ***9.1***	0 ***0***	2.9 ***0***
3	I enjoyed presenting the results of my project to other students in the class	26.5 ***24.2***	26.5 ***27.6***	29.4 ***29.3***	17.6 ***18.9***	0 ***0***
4	Sufficient time was allocated to the project over the semester	26.5 ***28.2***	67.6 ***65.9***	5.9 ***5.9***	0 ***0***	0 ***0***
5	I felt that I could access extra information from technical and academic staff when I needed it	0.0 ***9.1***	73.5 ***66.7***	20.6 ***21.2***	5.9 ***3.0***	0 ***0***
6	My group had sufficient time using the data trolleys and laboratory space to complete the project requirements	8.8 ***6.1***	58.8 ***69.7***	23.5 ***24.2***	5.9 ***0***	2.9 ***0***
7	The laboratory sessions provided me with the skills and information required to tackle the group project	14.7 ***18.2***	67.6 ***72.7***	17.6 ***9.1***	0 ***0***	0 ***0***
8	Presentation of the project allowed me to demonstrate what I had learnt in this subject	8.8 ***3.1***	47.1 ***72.7***	35.3 ***24.2***	8.8 ***0.0***	0.0 ***0***
9	The group that I was a member of worked and cooperated well together	29.4 ***3.0***	61.8 ***69.7***	5.9 ***18.2***	0 ***9.1***	2.9 ***0***
10	In my group all members made an equal contribution to achieving the project goals	17.6 ***12.0***	50.0 ***66.7***	14.7 ***21.2***	11.8 ***3.0***	5.9 ***0***

SD= Strongly disagree, D = Disagree, N = Neutral, A = Agree, SA = Strongly agree

Table 4: Unit Questionnaire (Results in percentages, 2003 result in bold italics)

Questions one and two indicate that broadly, the students found that the project fulfilled the aims of both helping them to understand and apply the theoretical coursework, and that they achieved more as a group than they could have individually. The common problem of distribution of tasks within the group was highlighted by question 10, indicating a wide spread of opinion on whether the group work was spread evenly amongst members. After refinement this result improved in 2003, when the course both had greater emphasis on group work, and students had a formal forum through self-reviews of project progress to discuss issues with academic staff. The increased focus and training in group dynamics resulted in students feeling that they had achieved more from the group project.

Conclusions

This paper provides details of the ongoing development and integration of a new unit called "Experimental Design and Analysis" into the engineering degree program at the University of Tasmania. The unit was initially introduced into the second year engineering course in 2002 and was refined for delivery in 2003. In 2004 it was moved into first year to provide a better introduction to design for new students. The unit is now designed to build on an earlier introduction to the multidisciplinary nature of engineering projects, and to provide the students with experience in working in teams to complete such projects. The group project was run throughout the semester, and students were able to work at their own pace using resources available in the laboratories. A lecture series was run in parallel to provide students with formal instruction on aspects of the project throughout the semester.

Students were surveyed and analysis of feedback from the first delivery of the unit indicated that the students enjoyed the experience and that they had achieved more working in groups than they could have individually. Refinement of the subject led to an increase in the amount of formal instruction in group dynamics and a requirement that the student teams be allocated by staff, rather than from 'clique' groups. The balance of group and individual assessment was altered to increase the level of individual assessment. This has been done carefully, to ensure that the students maintain an emphasis on building group work skills as a major learning outcome of the unit.

When delivered to first year students from 2004, the unit maintains the focus on the concepts of team work, the nature of multidisciplinary projects and the application of creative design within the boundary of engineering principles. The technical content of the subject has been modified to make it suitable for first year students. With these adjustments, the unit enables students to commence their degree program with explicit knowledge of the school's expectations for group work and laboratory practice and the experience to be able to achieve these expectations.

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Biographical Information

Professor Frank Bullen has lectured and practised in four countries and has an extensive publication record with over 100 articles in international and national technical journals, conferences, symposiums and workshops. Frank's research involves innovative teaching and learning approaches and the technical areas of pavement materials and design, soil stabilisation and characterisation of fibre reinforced concrete.

Dr. Jane Sargison is a Postdoctoral Research Fellow. Her research involves novel approaches to teaching and learning, and the technical areas of experimental measurement techniques, turbomachinery and fluid dynamics (computational and experimental).

Mr. John McCulloch is a technical officer in the school in the area of electronics who also teaches into design units. John provides innovations throughout the school in laboratory development and instrumentation and currently holds concurrent appointments as a teacher and technician.