Fostering Creative Problem Solving and Collaborative Skills Through Impromptu Design in Engineering Design Courses

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Abstract

There is an increasing recognition of the importance for universities to develop curricula that fosters creative problem solving and collaborative teamwork skills as a key element of an engineering degree program. The historical emphasis on convergent thinking skills that currently dominates engineering tertiary education is seen as an imbalanced response to the skill sets necessary for design innovation, both individually and within sophisticated multidisciplinary teams, just when they are needed most. Such skills are highly valued by employers, and their development needs to be actively encouraged and facilitated by engineering educators. The role that synthesis or creativity plays in design is a much overlooked aspect in engineering education largely due to the perception that there is a lack of scientific rigour associated with divergent thinking and collaborative skills. Over the past three years a learning activity referred to as 'Impromptu Design' has been utilised in a first year design course at the University of New South Wales Mechanical and Manufacturing Engineering degree program. Impromptu Design provides a first concrete experience in an implementation of Kolb's Experiential Learning Model as a major pedagogical approach for the design course. The objectives of this approach include the development of divergent thinking skills in engineering students and the improvement of the first year experience in enjoyment of the intellectual excitement and challenge of studying in their field. Impromptu design competitions are a very effective starting point in the model for engaging students in problem identification, formulation, solution and group work, as well as providing an opportunity for students to develop a sense of identity with the discipline and meet other students in the course.

Introduction

The exponential growth in information and knowledge that has occurred in only the last 40 years has serious implications for tertiary educators in engineering. The predominantly used lecture-based teaching model that is based on information transfer is unable to cope with both the balance between increasing technical content and student's retention of this content as well as the experiential nature of design learning. This dilemma provides a challenge for engineering design educators to revise old methods of teaching that establish relevance to the engineering context and subsequent course material that the students will encounter and that focus on students' ability to more fully explore the problems that they encounter with higher levels of cognitive skills which emphasise a wider understanding of the relationships of the elements of a problem rather than simply focussing on data and facts. The learning paradigm of the reflective engineer proposed by Schön[1] suggests a learning process where students are encouraged and facilitated to understand the role of analysis and problem modelling in the overall problem solving process. Project Based Learning (PBL) has emerged as the most

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promising platform for constructing multidisciplinary learning environments and improving creative problem solving skills for design education. There are however, some difficulties inherent in this approach such as; non-uniformity of learning outcomes, high level of required resources and achieving coherence of foundational knowledge within such a dynamic environment[2].

Several reports have suggested that employers perceive engineering graduates to have insufficient problem solving, creative thinking and communication skills[3,4,5]. This perception is being addressed by the Faculty of Engineering at the University of New South Wales through a planned restructuring of the curricula that emphasises the importance of design skills in all four years of an engineering degree. This will require a much more concerted effort towards developing methods of effective learning that can produce graduates that have higher levels of design skills such as reflective thinking, creative and innovative approaches to problem solving (both individually and in teams) and communication skills (with a particular emphasis on visualisation and interdisciplinary grammars)

The attribute of student engagement in first year curriculum design is also increasing in importance to effect improved student retention rates and overall student satisfaction. Engaging students is essential in ensuring that future graduates leave university with an impression that their experience of their education was both an intense and rewarding learning experience[6]. Moreover, in the current Australian climate of government funding directed towards achieving demonstrated quality student outcomes, there are obvious economic implications for Australian universities. The development of a project based learning environment that utilises a larger component of experiential practice will engage students much more effectively then currently is the case by providing an environment of active participation. Ramsden[7] suggests that "When our interest is aroused in something, whether it is an academic subject or a hobby, we enjoy working hard at it.

The benefits of engaging students with inspirational, creative and innovative approaches to engineering design problem solving in a real world context also result in a deeper learning experience which offsets the tendency for students to collapse into the narrower convergent thinking styles that result from an over focus on scientific techniques as opposed to more holistic approach to open-ended problem solving. Gibbs[8] suggests that the general aims of study in higher education should be focused on "the development of students' intellectual and imaginative powers; their understanding and judgement; their problem-solving skills; their ability to see relationships within what they have learned and to perceive their field of study in a broader perspective. The programme must aim to stimulate an enquiring, analytical and creative approach, encouraging independent judgement and critical self-awareness."

The development of the techniques discussed in this paper occurred within the framework of a first-year engineering course entitled Mech1120-Design and the Engineering Profession. The desired learning outcomes for this course were defined to address the above mentioned issues and framed within the attributes outlined by the professional engineering body the Institute of Engineers Australia and the recently revised graduate attributes policy at UNSW. The outcomes relevant to this course then, are that upon entering the workforce as professional engineers, students should have the ability to:

- Utilise creative and imaginative problem solving approaches;
- Collaborate effectively in team based problem solving;
- Communicate effectively

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- Utilise a systematic approach to design problem solving

First year in particular, presents an opportunity to positively influence the direction and attitudes that students adopt in their university and subsequent professional careers. In additional to achieving the above learning outcomes, the course was designed to enhance the learning experience in ways that the students perceived as exciting, challenging, interesting, fun and relevant.

Description of the Impromptu Design Activity

The activity was undertaken by over 240 first year engineering students enrolled in the Mech1120 course at UNSW in the second week of first session from disciplines including mechanical, manufacturing, aerospace, and mechatronics engineering. Of these, about 25% were from non-English speaking backgrounds and an equal number from interstate areas within Australia.

Prior to the activity, students were randomly divided into groups of eight, meaning that each student had the opportunity to meet at least seven students in the course. Each group was given a bag of materials, some tools, an egg, and a specification sheet containing the problem description including all of the rules and constraints that limit the solution space. The sheet also provides suggestions related to group processes, for example, it was suggested that students begin by planning their activities including allocating roles and responsibilities to the members of their group as well as documenting the activity. The materials that each group received vary from year to year and generally include cardboard, paper, pasta, super glue, twine, scissors, a small piece of sponge, sticky tape, cotton balls, and rubber bands (Figure 1).

The task simulated the designing, building and testing of a bus shelter to protect the life of an occupant (the egg) that could withstand the impact of a model truck along a ramp (2m long at an angle of 45 degrees with a hard stop at the end). A diagram of the testing ramp was provided, and students had access to the model truck that was used in the testing phase.

Figure 1 Materials given to each group for the impromptu design task

Students were given one hour to design, build and test their solution. Any breakage of the egg was considered a failure. A week later, students were asked to submit a 500-word report on

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the impromptu design activity (the assessable component of the task) which required them to reflect on their task performance, including both their experience of the design process and their performance as a team.

Figure 2 Students' design on the testing apparatus

Tutors were provided for students during the session to answer questions, simulating the process of interaction with a client in industry. In addition to interacting with tutors, students had to engage in various forms of communication such as dialogue with each other, visual communication (sketches to illustrate their ideas) and report writing.

Pedagogy

The problem of implementing an experiential approach to teaching design is complicated by the need to provide a coherent framework for effectively incorporating both foundation knowledge in the form of lectures as well as applied knowledge in the form collaborative teams engaged in the activities surrounding the design process. Kolb's Experiential Learning Cycle[9,10] presents itself as an intuitively correct model for achieving these aims. The model also provides an opportunity to provide a Concrete Experience that with subsequent Reflection can emphasise the Divergent Knowledge elements that broadly relate to creativity (Figure 3). These are the "private" and internalised parts of the cycle which lend themselves to an explication of the cognitive steps that are defined by a design methodology. This reflection can then be utilised in encouraging student designers to follow a procedure that addresses both the art and science of design problem solving.

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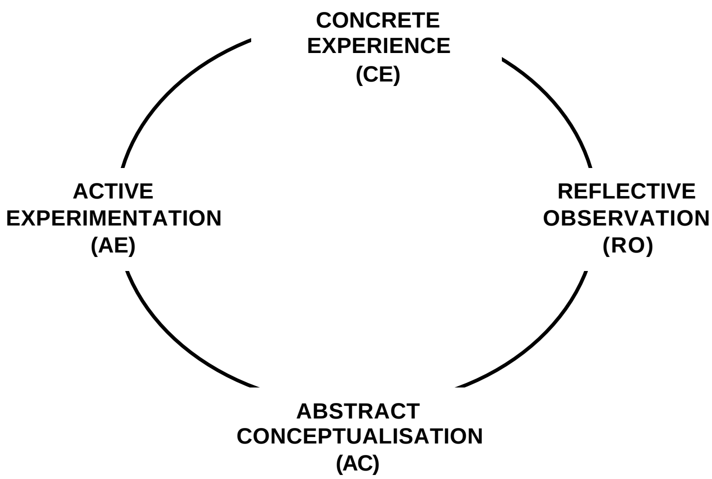

Figure 3 Adaptation of Kolb's Experiential Learning Cycle

While the Impromptu Design task provided students with a hands-on (concrete) experience and introduced them to group work and problem solving processes in design, other key elements in the course gave students an opportunity to reflect and build on this experience. The additional components of the course are briefly described below, and are expressed in terms of the remaining elements of Kolb's Experiential Learning Model.

Online discussions and the written report (observation and reflection)

A WebCT (online web-based learning software) site was established to allow students to engage in reflective discussions with peers about their experience of the Impromptu Design task. Each group was required to take a picture of the team and the prototype design using a digital camera, and these photos were included in students' written reports and on the course website for students to view and discuss.

The written report was the students' first introduction to the structure required for an engineering report at university level. Several lectures were provided to emphasise the critical importance of written communication in engineering and to support them with structuring the report in accordance with guidelines which were placed on the course website. The report asked students to describe (in 500 words) their design experience by comparing it to the prescriptive design process provided in the text. Students were asked to provide at least one sketch of their solution in the report, comment on why their solution took the form it did, why they thought it would be successful, and any difficulties they encountered in organising their team to achieve the objectives. Finally, students were asked to list the roles and responsibilities of their group members in relation to the task.

The lecture series (abstract conceptualisation)

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The lectures were, in part, designed to support students' development of abstract concepts. The areas covered in lecturers included:

- Planning your design effort
- When to ask questions
- Cooperating/conflict resolution/teamwork
- Exploring solutions
- Design methodology

The Impromptu Design task provided a central point from which the lecturer could emphasise key ideas and reinforce important concepts in ensuing lectures. In addition, the lecturer was able to demonstrate why the most successful group design worked by using an analytical model in the lecture.

The impromptu design task provided a basis from which the lecturer could emphasise these concepts and explain the importance of developing effective group work skills in the context of design Engineering.

Second design task (active experimentation: testing in new situations)

The second design task occurred over 10 weeks of the session. The groups established for the Impromptu Design task were maintained to provide continuity and to give students the opportunity to further improve group processes. The objectives of the project were to construct a one metre long pasta bridge over a ravine that would support a test truck passing over the bridge. Students were given three attempts in which they nominated the payload that the truck would carry over the bridge.

Impromptu Design is used predominantly as an icebreaker but has little reported use within engineering design education curricula. The University of Houston uses an Impromptu Design competition as a component of a multidisciplinary capstone design course to improve camaraderie. Michigan State University has reported using Impromptu Design as a team training experience supported by a lecture and written evaluation of individual and team strengths/weaknesses within a senior level Heat Transfer Laboratory Course[11]. The author is unaware of any research or educational projects using Impromptu Design activities as an element of a structured learning approach based on Kolb's Experiential Learning Model.

Results

To evaluate the role and effectiveness of the impromptu design task and other elements of the course, focus groups were conducted at the end of the course in both 2003 and 2004. The participants formed a sample population of (n=6, 6, 6, 7, total n=25) and were broadly representative of the demographics of students enrolled in the course, with 20.0% (n=5) international students and 20.0% female (n=5). The students were asked to describe their experience of the impromptu design task. Questions were designed to provide information about how they approached the design problem, the most difficult and interesting aspects of the task, and their experience of working in groups to achieve the objectives. Further questions were designed to collect information about whether students were able to make connections between various aspects of the course, and to see what particular skills students felt they developed. In addition, the questions were designed to find out what abstract

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concepts students gained from their design experience. A select number of key themes are presented here along with key quotes to demonstrate common perceptions.

Designing the task to promote student initiative and problem solving

"I think that all through the course (the lecturer) didn't really give us clear instructions for anything and I think the whole point of it was that he was not going to and he did not mean to – because if you don't give people instructions then they have to work it out for themselves to the best of their ability."

An important aspect of this task was the need to emphasise the vital importance of asking questions[2]. Our observations are that this is a skill that is not adequately understood by students in their first year. Students must be able to know when to ask questions to clarify a problem and any assumptions whilst simultaneously engaging in generating and evaluating as many solutions as possible. Therefore, leaving information out was essential in teaching students the importance of defining the problem space.

Experiential learning

"I think there are some things that lecturers cannot teach that you have to sort of be in the position and experience and see it for yourself and then judge and act accordingly…"

"I think it was good that we got to see it work instantly… not something that's going to happen a few months down the track. You know, we design it, we test it, see if it works…"

"I feel that in terms of design we really learnt a lot just from our own experimentation"

The quotes above suggest that students recognized the benefits of working in groups on design problems through hands-on experience. There was also evidence that the report writing and WebCT discussions provided opportunities for students to reflect on both their experience of the design process and working in groups. Several comments made by students however suggested that further opportunities for reflection would be useful in supporting their learning.

Development of team work skills

"We were put in a situation that forced us to bond as teams, find out names and everyone had to work together"

"Team work was the main idea of this whole project – working with people and how to go about treating other people."

"I think that the egg project was good in identifying who wanted the group to go well – it was good at identifying roles."

"…it was good to put us in those groups because ultimately as engineers, that is what we are going to have to do, I mean we are not going to be working in pairs – that is what it is going to be like."

Feedback from students clearly indicated that the Impromptu Design task had a positive impact on the development of team work skills and their ability to solve problems in groups.

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There was a perception amongst students that the groups were too large. However the students did recognize that the size of the groups reflected the reality of the workplace. In addition, larger group sizes challenged students in the area of group management and conflict resolution. In terms of the formation of groups, students generally agreed that being randomly put into groups was positive because it enabled them to mix with a broader range of students. One student made the comment "if you're going to have that arbitrarily assigned group environment, first year first semester is the time to do it." In the second half of their first year, students are given the opportunity to select their own group members for a 'Reverse Engineering' project in the Introduction to Manufacturing course. This provides an excellent 'testing in new situation' experience regarding group development and performance. Informal feedback on this experience suggests that students develop a deeper insight into group dynamics and appreciate the benefits of having already established a performing group and acquired additional networks amongst their peers.

The importance of planning in the design process

"I think it was good because everyone just got thrown in and you had such a short time to do it, and you had to really try and coordinate everything to get it completed in time… I think it… prepared us for the later stages of the course – seeing what each group member was capable of, how they work together as a group"

Planning is an essential skill, not only in engineering but in life in general. The Impromptu Design activity, whilst artificially contrived, condenses the design experience for students and brings out the learning objectives in a real way. It allows students to engage in the team development process of forming, storming, norming, and performing.

The acquisition of new skills and abstract concepts

"It really impacted our understanding of properly defining our problem"

"…specific constraints made the project very, very hard. But looking at it in hindsight I'm glad that it was a difficult project to solve…problem solving as a practical thing I found really good"

"We really weren't sure how to start – everyone was making suggestions… I suppose there was a lot of creativity, like we were just trying several things…"

As suggested in these quotes, students developed an appreciation for the importance of problem definition and the role of questioning in Engineering design, and their comments suggested that they viewed problem solving as both a structured and creative process.

Identification with the discipline

"It definitely did help me make some of that mental shift… shift towards more of an Engineering mentality"

"It really made you have something to look forward to about being an engineer."

Students agreed that the impromptu design task and subsequent hands-on activities in the course helped them to understand the relevance of what they were learning and relate it to a

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professional context. Through their comments, students demonstrated that they had developed an understanding of how some of the group work issues they faced in the task might be experienced in the Engineering profession.

A follow up survey was conducted in 2005 (Table 1) to gain additional data and cross check the results obtained from the previous two years. This brief survey was carried out in week 9 of the course to nullify any potential bias from post-competitive excitement and to ensure the results were focused on the Impromptu Design activity only and no t the second Pasta Bridge design activity. By this time students had been given lectures on design, project management, and teamwork and had also experienced lectures from other courses. The total sample population was n=90 and was constructed on a scale o f 1-4 with Strongly Agree 4, Agree 3 Disagree 2 Strongly Disagree 1. The results were collated as a percentage with Strongly Agree equating to 100%. The responses clearly indicate that the Impromptu Design activity brought out the significance of teamwork to design as well being seen as a fun and interesting approach to learning design.

% Agree	The Impromptu Design Activity:
90	Was a more effective means of learning design than traditional lectures
83	Helped me appreciate the need for effective teamwork in design projects
80	Was fun and exciting
79	Was interesting and challenging
78	Helped me appreciate the importance of good time management
77	Helped highlight the importance of creativity in engineering
74	Was a good way to break the ice and get to know my peers
73	Helped me to appreciate the need to ask questions to properly define the problem
70	Helped highlight the relevance of acquiring analytical skills in subsequent years
61	The written report changed the way our team approached the pasta bridge design task

Table 1 Results of 2005 Student Survey

Discussion and Conclusions

Based on observation, students' progress throughout the session, and the data collected over the past three years, the Impromptu Design task is viewed as a successful vehicle for introducing students to the role of effective group work and problem solving skills in the context of Engineering design. Impromptu Design has a number of advantages in terms of student learning. The short time frame in which students were required to complete the task meant that the focus was intense, and they had to organize themselves quickly in terms of group roles. A clear goal and a tight deadline are two essential elements of successful innovative teams[12]. Importantly, the task alerted students to the importance of asking questions which is seen as, "a fundamental cognitive mechanism in design thinking"[13].

The task is particularly suitable for first year students because it allows them to get to know their peers, it is considered to be a fun, exciting and challenging activity, it allows students to be creative (to engage in conceptual thinking without necessarily having the analytical knowledge), and provides students with an experience that they can then reflect and build on at various stages throughout the course. The impromptu design task presents an opportunity to demonstrate to students the relevance and importance of acquiring analytical and modelling skills, and to enhance their creative skills in designing an engineering artefact.

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Recent research on cognitive mechanisms in design thinking (in particular studies carried out by researchers at the Centre for Design Research at Stanford University)[14] has important implications for learning and teaching methods in Engineering, and supports further investigation into novel experiential learning activities such as that described here. In conjunction with the pedagogical literature, such research provides an opportunity to further develop and evaluate teaching approaches and to strengthen links between teaching and research in the discipline.

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