Impromptu Design as a Vehicle for Developing Team Work and Problem Solving Skills in Design Engineering

Authors:

Carl Reidsema, University of New South Wales reidsema@unsw.edu.au
Clare Netherton, University of New South Wales c.netherton@unsw.edu.au
Stephanie Wilson, University of New South Wales stephaniewilson@unsw.edu.au

Abstract — *Design Synthesis is a mixture of art and science, and as such is still poorly understood. Engineers today are often physically divorced from the process of making an object. The last century has seen the disappearance of the engineer as craftsman and manufacturer and this al ienation from the object of design places an even greater importance on understanding (and thus teaching) the how of design. A current focus of design engineering education is in the development and assessment of students' design problem solving skills bot h individually and in teams that incorporate creative and rational aspects of reflective practice. Success in this area is seen as critical to any significant improvements in the quality of engineering design education and is best implemented in the first -year curriculum. Several reports have suggested that employers perceive engineering graduates to have insufficient problem solving, creative thinking, team work and communication skills. New competitive strategies for industry such as Concurrent Engineerin g which place critical importance on collaboration between participants from many disparate areas of expertise suggest that demand for these skills is only likely to increase. This paper discusses the role of Impromptu Design as an activity within an Exper iential Learning Framework that focuses on developing these skills as well as encouraging students to enjoy the intellectual excitement and challenge of studying in their field in ways that the students perceived as exciting, interesting, fun and relevant.*

Index Terms — Design Education, Experiential Learning, Graduate Attributes, Impromptu Design

INTRODUCTION

Design Synthesis is a mixture of art and science, and as such is still poorly understood [1]. Engineers today are often physically divorced from the process of making an object and students arrive at university with little or no experience with mechanical devices. The last century has seen the disappearance of the engineer as craftsman and manufacturer and this alienation from the object of design places an even greater importance on understanding (and thus teaching) the *how* of design. There is also an increasing awareness of the importance of developing and assessing students' problem solving skills throughout their degree, including both the creative and cognitive aspects of these skills. Such skills are highly valued by employers, and their development needs to be actively encouraged and facilitated by engineering educators. There appears to be a great deal of conjecture on whether creativity and innovation (both of which are essential traits of good designers) can be taught at all. One thing though that is consistent in the literature is that innovation and creativity are more effectively experienced in teams and require a conducive environment from which to grow [2]. This paper discusses the role of Impromptu Design as a seeding activity within an Experiential Learning Framework that focuses on developing these skills in first year engineering students as well as encouraging them to enjoy the intellectual excitement and challenge of studying in their field. Impromptu design competitions are a well known and very effective experiential method of engaging students in problem identification, formulation and 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. [1]Quite often they are used as "ice-breakers" for breaking down barriers to effective management and highlighting the importance of teamwork within industry.

INSTITUTE OF ENGINEERS AUSTRALIA (IEAUST) AND UNSW GRADUATE ATTRIBUTES

[1] Such competitions are employed by a large number of institutions including Purdue University, Old Dominion University, University of Houston, University of Kansas, American Society of Mechanical Engineers (ASME), American Society of Civil Engineers (ASCE), and are even offered as a compulsory subject at Leipzig University of Applied Science for their Architecture degree.

Several reports have suggested that employers perceive engineering graduates to have insufficient problem solving, creative thinking and communication skills [3,4,5]. New competitive strategies for industry such as Concurrent Engineering which place critical importance on collaboration between participants from many disparate areas of expertise, lend support for this perception [6].

The development of this study 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 developed in accordance with the attributes outlined by the professional engineering body the Institute of Engineering Australia (IEAust)[7]. The outcomes relevant to this course are that, upon entering the workforce as professional engineers, students should have the ability to:

- Communicate effectively
- Undertake problem identification, formulation and solution
- Utilise a systems approach to design
- Function effectively as an individual and in teams.

These skills are also strongly reflected in the recently revised graduate attributes policy at the University of New South Wales (UNSW), which states that students should develop skills such as the capacity for analytical and critical thinking and for creative problem solving, the skills required for collaborative and multidisciplinary work, and the skills of effective communication [8]. First year in particular, presents an opportunity to positively influence the direction and attitudes that students adopt in their university and subsequent professional careers. The following statement from Brendan Parker, Dean of the Faculty of Engineering at UNSW, also suggests the need to focus on the role of creativity in problem solving early in the education of engineering students:

"To produce well -rounded graduates capable of taking on the diversity of careers that engineering offers we need more emphasis on the creative side of engineering, with a broad approach to design beginning early in the programs."

In this study, the impact of the Impromptu Design task on student learning was considered from a number of perspectives. The areas of the literature examined include recent research on the development of graduate attributes, in particular problem solving and group work skills; the role of active and experiential learning; and research on the process of engineering design and its implications for education.

The procedure that was introduced to the students was a common prescriptive design methodology [1]. In this methodology (Figure 1), the problem definition and specification phases are concerned with problem setting and the conceptual phase relates to problem solving. SchÖn (1983) has emphasised that when engaged in design activity, a reflective practitioner behaves as if problem setting is as important as problem solving [9].

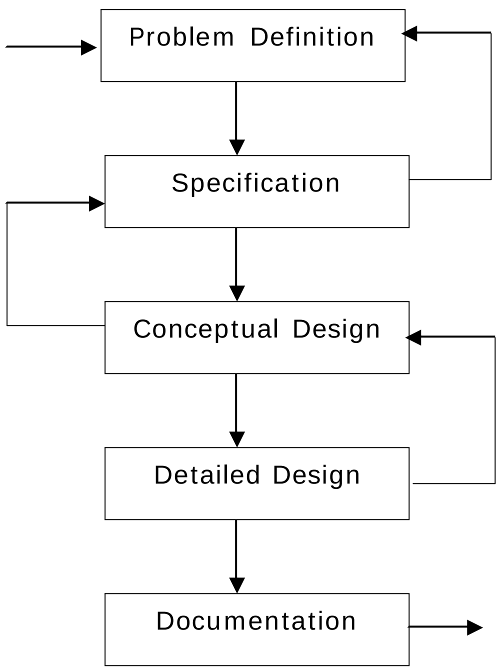

FIGURE 1
PRESCRIPTIVE DESIGN METHODOLOGY

The problem of teaching design is even more complicated by the need to consider issues related to collaborative or team-based design. Kolb's Experiential Learning Cycle [10] suggests an opportunity to provide a Concrete Experience that with subsequent Reflection can emphasise the Divergent Knowledge elements that broadly relate to creativity (Figure 2). 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.

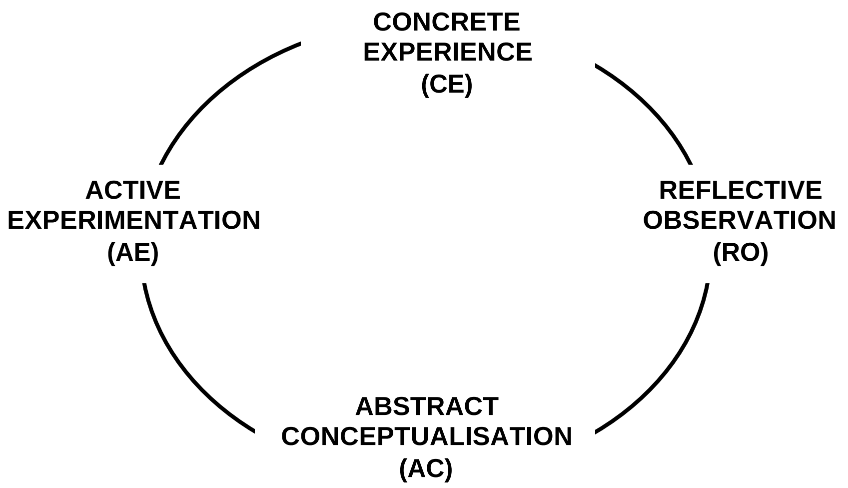

FIGURE 2
ADAPTATION OF KOLB'S EXPERIENTIAL LEARNING CYCLE

A consideration of the educational literature suggests that attributes such as problem solving and team work skills are best learned in a disciplinary context. For example, Bowden et al [11] states that the "development, practice and assessment of [graduate attributes] are most effectively achieved within the context of disciplinary knowledge" (p.1). In addition to highlighting the importance of context, the educational literature provides evidence that graduate attributes are learned most effectively when students have the opportunity to engage in both observation and reflection [12, 13]. Such opportunities allow students to make connections between various aspects of their learning experience and develop theoretical understandings. This process is articulated in Kolb's [10] Experiential Learning Cycle (Figure 2).

While there are a number of limitations associated with Kolb's model[2], it does highlight the importance of experience, reflection, the development of conceptual knowledge, and giving students the opportunity to test their knowledge in new situations. This concurs with Gibbs, Rust and Jenkins [13] who emphasise that "students do not become proficient in the use of a skill simply by being told about it, discussing it or thinking about it – they have to practice the skill" [p.13]. This approach is also supported by Kelley [2] and Michalko [14]. The impromptu design task presented to students early in the course represents the "concrete experience" aspect of the model.

The curriculum of the course *Mech11 20-Design and the Engineering Profession* is designed to have students achieve a number of fundamental learning aims such as:

- introduction to the engineering profession
- instilling an appreciation of the importance of communication in engineering life
- introduction to engineering hardware and components
- introduction of a methodology for design problem solving and decision making within groups.

Of these, the Impromptu Design activity focused on instilling an appreciation of the importance of communication in engineering life and an introduction of a methodology for design problem solving and decision making within groups in particular.

---

[2] Limitations of the model have been identified by a number of authors. These include its linear nature and the fact that it does not explicitly account for student diversity. It is acknowledged that while the components included in the model are important, they do not necessarily occur in the order presented (they may happen simultaneously), and are not necessarily given equal time or emphasis.

The course responds to a number of further perceived issues in student learning as well as the graduate attributes:

- Students need support in forming relationships with other students from their chosen discipline.
- Students need to understand the relevance of gaining analytical skills in preparation for subsequent years.
- Students need to understand why group work skills are relevant to the discipline.
- Students are often unaware of problem solving as a process/method.
- Students often do not appreciate the importance of time management.
- Students are not always sure of how and when to ask questions.

In addition to introducing students to problem solving, group work and communication skills in Design Engineering, the impromptu design task described in this paper was developed to encourage students to enjoy the intellectual excitement and challenge of studying in their field, and support students in developing a sense of belonging to their discipline community. The course was designed to enhance the learning experience in ways that the students perceived as exciting, challenging, interesting, fun and relevant.

IMPROMPTU DESIGN TASK

This study includes students who undertook the Mech1120 course at UNSW in the years 2003 and 2004. Students were mostly first year, first session mechanical, manufacturing, aerospace, mechatronics engineering students. Of these, about 25% were from non-English speaking backgrounds. Within two weeks students participated in the learning activity referred to as "impromptu design".

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 sheet containing the problem description including all of the rules and constraints that limited the solution space. The sheet also made some 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. The materials that each group received included cardboard, paper, pasta, super glue, twine, pegs, scissors, Exacto knives, a sponge, sticky tape, an egg carton holder, blu-tac, cotton balls, cigarette filters and rubber bands (Figure 3).

The task simulated the designing, building and testing of a bus shelter to protect the life of an occupant (the egg) that would 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.

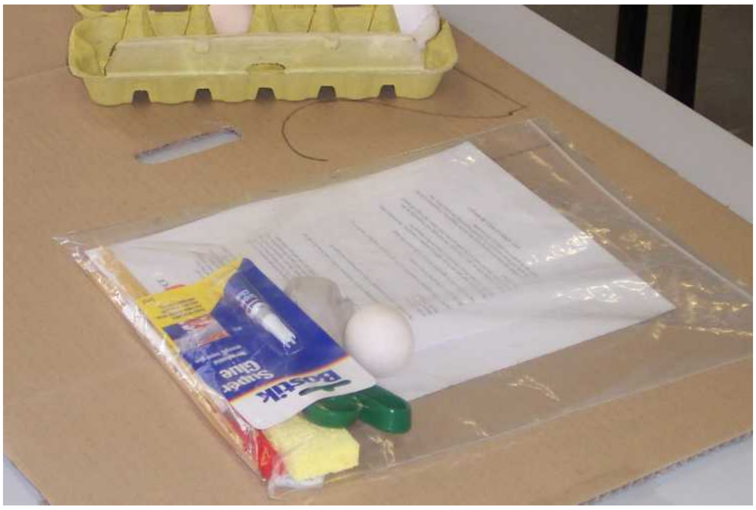

FIGURE 3
MATERIALS GIVEN TO EACH GROUP FOR THE IMPROMPTU DESIGN TASK

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 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 4
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.

RELATIONSHIP BETWEEN THE IMPROMPTU DESIGN TASK AND OTHER COURSE COMPONENTS

While the impromptu design task provided students with 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 (see Figure 1)[10].

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)

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.

FEEDBACK AND EVALUATION

To evaluate the role and effectiveness of the impromptu design task and other elements of the course, focus groups were conducted in both 2003 and 2004. Focus group participants (n=6, 6, 6, 7, total n=25) were broadly representative of the demographics of students enrolled in Mech1120, with 20.0% (n=5) international students and 20.0% female (n=5). Students (n=25) were asked to describe their experience of the impromptu design task. Focus group questions were designed to provide information about how students approached the 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 concepts students gained from their design experience.

The focus groups provided a rich source of information about many aspects of student learning in the course. For the purpose of this discussion however, only 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. 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.

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, performing, and adjourning [15].

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 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.

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. 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.

DISCUSSION AND CONCLUSIONS

Based on observation, students' progress throughout the session, and the data collected in the student focus groups, 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 design Engineering. The impromptu design had 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 [2]. Importantly, the impromptu design task alerted students to the importance of asking questions, "a fundamental cognitive mechanism in design thinking" [16]. This is supported by Pasarella and Terenzini [quoted in 17], who highlight that "greater learning and cognitive development occur when students are closely engaged and involved with the subjects they are studying" (p.22).

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.

Recent research on cognitive mechanisms in design thinking (in particular studies carried out by researchers at the Centre for Design Research at Stanford University) [16, 18] has important implications for learning and teaching methods in Engineering, and supports further investigation into 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.

REFERENCES

[1] Cross, N., *Engineering Design Methods: Strategies for Product Design, 3rd edition*, John Wiley and Sons, 2000
[2] Kelley, T., *The Art of Innovation*, Doubleday, New York, NY, 2001
[3] DETYA (Department of Education, Training and Youth Affairs) *Higher Education: Report for the 2000 to 2002 triennium*. Canberra: 1999
[4] Institution of Engineers, Australia (IEAust) (1996b). *Changing the culture: Engineering education into the future* (Task Force Reports). Barton, ACT: IEAust.
[5] Selinger, C. "Stuff You Don't Learn in Engineering School", *IEEE Spectrum,* September 2003, pp. 49-52.
[6] Prasad, B. *Concurrent engineering fundamentals: integrated product and process organisation*. Prentice-Hall International Series in Industrial and Systems Engineering, 1996
[7] UQ Engineering: *Graduate Attributes – IEAust*. University of Queensland. URL: http://www.eng.uq.edu.au/page.asp?pageid=8&m=2 (accessed 1 October 2003).
[8] UNSW Graduate Attributes Policy (2003), University of New South Wales.
[9] SchÖn, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. Basic Books.
[10] Kolb, D.A. (1984). *Experiential Learning : Experienc e as the Source of Learning and Development.* Prentice-Hall.
[11] Bowden, J., Hart, G., King, B., Trigwell, K. and Watts, O. (2000) *Executive Summary, Generic Capabilities of ATN University Graduates*, URL: http://www.clt.uts.edu.au/TheProject.htm#Executive.Summary (accessed: 23 March 2004).
[12] Boud, D., Keogh, R., and Walker, D. (1985). *Reflection: Turning experience into learning*. London, Kogan Page.
[13] Gibbs, G., Rust, C., Jenkins, A. and Jacques, D. (1994). *Developing Students Transferable Skills*. Headington, Oxford: The Oxford Centre for Staff Development.
[14] Michalko, M. (1998). Cracking Creativity, The Secrets of Creative Genius, Ten Speed Press
[15] McGourty, J. and De Meuse, K.P. (2001). *The Team Developer: An Assessment and Skill Building Pro gram.* John Wiley & Sons, Inc.
[16] Eris, Ö. (2003). Asking Generative Design Questions: A Fundamental Cognitive Mechanism in Design Thinking. *Proceedings of the International Conference on Engineering Design*, Stockholm, Sweden.
[17] Wilson, S., Scoufis, M. & Weiss, B. (Eds.). *Exciting and Engaging our Students in their First Year at UNSW*, Learning and Teaching @ UNSW, 2003.
[18] Milne, A. and Leifer, L. (1999). The Ecology of Innovation in Engineering Design, *International Conference on Engineering Design,* ICED99 Munich, August 24-26, 1999