More than Just a Game: The Role of Simulation in the Teaching of Product Design and Entrepreneurship to Mechanical Engineering Students

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The purpose of this work is to contribute to the debate on the best pedagogical approach to developing undergraduate mechanical engineering skills to meet the requirements of contemporary complex working environments. The paper provides an example of using student-entrepreneur collaboration in the teaching of modules to Mechanical Engineering final year students. Problem-based learning (PBL) is one of the most significant recent innovations in the area of education for the professions. This work proposes to make an original contribution by simulating a real-life entrepreneur interaction for the students. The current literature largely confines simulation -based learning to computer applications such as games. However this paper argues that role playing by students interfacing with technology start-ups can also be regarded as "simulation" in a wider sense. Consequently the paper proposes the concept of simulation-action learning (SAL) as an enhancement of PBL and to distinguish it from computer simulation.

Keywords: product design, entrepreneurship, pedagogy, simulation, PBL, SBL

1. Introduction

This paper will provide an example of using student-entrepreneur collaboration in the teaching of modules in the Product Design stream of final year Mechanical Engineering Level 8 students at the Galway-Mayo Institute of Technology (GMIT), located in the West of Ireland. According to Boud and Feletti (1998) "problem-based learning is the most significant innovation in the area of education for the professions in many years" (p. 1). The focus in this type of learning is to provide the students with problem scenarios so that they can learn through a process of action and reflection (Savin-Baden 2003). However some scholars argue that design "is hard to learn and harder still to teach"(Dym *et al.* 2005). Furthermore organizations, such as Engineers Ireland, are calling for graduate engineers to have more rounded skills in the areas of presentation, communication and team-working (Engineers Ireland 2016). This paper builds on design thinking (Cross 2000, Otto and Wood 2001, Ulrich and Eppinger 2004) and brings it to a new level by directly interfacing with an entrepreneur and simulating a real-life entrepreneur interaction for the students. The purpose of the work is to contribute to the debate on the best pedagogical approach to developing undergraduate skills to meet the requirements of contemporary complex working environments.

GMIT opened two incubation centres in late 2005 and mid-2006. These Innovation Hubs were established with the support of Enterprise Ireland, and have a twofold objective; to support and facilitate the emergence of new market-led and knowledge-based companies in the region and, forge strategic links between the college and the world of industry and commerce. The Innovation hubs, at GMIT Mayo campus and Galway campus, offer incubation facilities and a supportive environment to potential entrepreneurs in order to assist them in taking their ideas from concept to full commercialization (Hub 2016). The author has worked with around twenty entrepreneurs over the last few years and the study is based on these cases.

The paper proceeds as follows. Firstly the background literature in the areas of problem-based and simulation-based learning is reviewed and related publications in engineering education journals are presented. Following this the methodology and the research approach is discussed. The implications of the study are then presented. Finally conclusions and recommendation for future work are proposed.

2. Literature Review

This section will begin with an overview of problem-based learning derived from the engineering education literature. It will then provide a review of simulation-based learning and argue that this study bridges a gap in the engineering literature.

The application of problem or project based leaning to the engineering discipline is frequently traced back to the Danish Tradition established in two universities in the 1970s. One of these, the Aalborg University Model (AAU), has been particularly influential on the development of the methodology. The theoretical basis is founded on the works of Piaget, Dewey, Lewin, and more recently Kolb (Kolmos *et al.* 2004). The approach is described as concerning “three dimensions: the problem, the content and the team” (ibid. p. 12). An important part of the development of the model has been the inclusion of “the student voice” (Jørgensen 2004). Furthermore the progress of the AAU is seen as a response societal change and its implications for education (Krogh and Rasmussen 2004) as well as the “new global realities” which are “at best described as ‘complex’ and ‘uncertain’” by Sørensen (2004 p. 110). According to Luryi *et al.* (2007), engineering programs increasingly endeavour to include entrepreneurship and innovation in their curriculum. There is a significant literature on problem-based learning in engineering education (Perrenet *et al.* 2000). The focus in this type of learning is to provide the students with problem scenarios so that they can learn through a process of action and reflection. The environment of engineering they contend has radically changed in the last decade driven by advances in information and communications technology. Furthermore, globalization of manufacturing and R&D (research and development) has had a significant impact on how engineers work. Among their recommendations is that engineering programs “should involve hand-on business experience based on innovating engineering projects" (Luryi *et al.* p. T2E-15). This study included a review of two major journals in the area of engineering education using the search word *entrepreneurship* that yielded the following results. The Journal of Engineering Education (JEE) had fourteen publications on the subject of entrepreneurship from 2001 to 2009 while the European Journal of Engineering Education (EJEE) had ten publications on entrepreneurship from 2000 to 2012. Examples from the former journal include: Ohland *et al*. (2004) which concludes that entrepreneurship programs add value to engineering students; Creed *et al.* (2002) who argued for a paradigm shift that requires the merger of classroom learning and industry participation and Mendelson (2001) who proposes joint projects between engineering and business students. EJEE publications include studies by: Silva *et al.* (2009) who argue that teaching product development in an entrepreneurship framework promotes students skills; Papayannakis *et al.* (2008) who contend that entrepreneurship teaching should be part of a more general discussion related to educational priorities and Casar (2000) proposes a synergy between research and education. These publications support the argument of this paper that direct collaboration between an entrepreneur and students has a strong pedagogical basis that goes beyond the traditional PBL model (Tan and Ng 2006). Furthermore it contributes to what Lappalainen (2011) terms the " ability for critical engagement and thought, interdisciplinary and original thinking, collaborative teamwork, and socialisation into the engineering community" (p. 513). Now, I will review the concept of simulation as part of the learning process and argue that it is relevant to the pedagogy of product design and entrepreneurship.

Simulation and Learning

The Oxford dictionary definition of simulation is as follows: to "imitate the appearance or character of" (ODE 2006). While the entry does refer to computer modelling as an application of simulation, I will use the broader definition to argue that the etymology of the word implies a much wider concept than that of computer modelling and the digital learning debates (Eck 2006, Prensky 2001).

Recently there has been a body of literature in the field of medicine on the subject of using simulation-based learning (SBL) as an enhancement of PBL (Cant and Cooper 2010, Lateef 2010, Steadman et al. 2006). PBL had its origins in 1968 in a medical program at McMaster University in Canada and subsequently was adopted in other disciplines such as engineering (Smith *et al.* 2005). Its influence on medical education and training is supported by the fact that Stanford has a Center dedicated to its study (CISL 2016). Simulation is being used to increase nurse's self-efficacy and skills (Fadale *et al.* 2014) while a review of simulation-based learning by Cant and Cooper (2010 p. 3) concludes that simulation "using manikins is an effective teaching and learning method when best practice guidelines are adhered to". In the area of surgery simulation-based learning models attempt to replicate an environment similar to real life surgical situation (Khunger and Kathuria 2016). Importantly for my argument, Lateef (2010) emphasises that simulation-based learning is a *technique* not a *technology* designed to "replace and amplify real experiences with guided ones, often "immersive" in nature, that evoke or replicate substantial aspects of the real world in a fully interactive fashion" . Consequently, this paper proposes to make a contribution by transferring the simulation concept from medicine to engineering education in a similar way that PBL migrated from medicine to engineering.

Recently the topic of simulation as a learning experience has emerged in the management literature where for example Lu *et al.* (2014) found that students considered SBL to provide a richer learning experience than conventional methods such as lectures. They also proposed that SBL addressed the increasing criticism with the management literature on the relevance of much educational pedagogy in the field. In the area of teaching entrepreneurship to management students the role of the teacher changes from that of a presenter to that of a "coach" (Cadotte 2014) which is also adopted in this engineering study. Deegan *et al.* (2014) in their paper on the role of simulation-based learning environments (SBLE) in public management curricula, proposed out that it addresses the genre of "wicked problems" and complexity which Lindblom (1959) had examined a few decades ago .

However any review of the literature must be cognisant of the words of Cooney and Murray (2008) that the debate continues on "whether or not entrepreneurship can be taught" (p. 19). Now I will briefly outline the research approach used in this study.

3. Methodology and Approach: Action Research

Action Research (AR) originated from the work of Kurt Lewin during the 1940s and has been summarised as an approach that "combines theory and practice (and researchers and practitioners) through change and reflection in an immediate problematic situation within a mutually acceptable ethical framework" (Avison *et al.* 1999). The application of AR has not been without controversy particularly in debates with positivist science on the justification and generation of knowledge. These arguments were addressed by Susman & Evered (1978) in their influential description of AR as consisting of a cyclical process involving five phases: diagnosing, action planning, action taking, evaluating, and specifying learning. The focus of AR is to address real-life problems through intervention together with the research objective of making a contribution to knowledge. Coghlan and Brannick (2005) emphasise the importance of the social and academic context in which action research is carried out. This theme is echoed in the work of Bob Dick (1993) which will have significant influence on the argument of this work especially when reflection is discussed later. Dick, an academic working in the field of psychology, proposes that the AR methodology has the twofold aim of action and research:

- *action* designed to bring about change in some community, organization or program
- *research* to increase understanding on the part of the researcher or the client, or both – and in many cases some wider community

Data gathering for the research was completed by means of the students providing feedback on the module using a structured template. Each student was asked to give or decline their assent on using the data for research purposes. Furthermore the students were given assurance that any data would be anonymous. Permission from the incubation centre entrepreneurs and managers to use the interaction for research purposes was obtained by email.

Now the results of using the concept of reflection in the context of the cases examined in this study will be discussed. The reflection by the lecturer, students and collaborating entrepreneur was distilled into a replicable educational process.

4. Discussion

Despite calls to leverage the competencies of campus innovation centres (MacMahon *et al.* 2010) there is little evidence of actual collaboration in the literature. Furthermore Mason and Arshed (2013) contend that "there is both little discussion in the literature on what experiential learning should take and a paucity of examples of experiential approaches to learning" (p. 449). This paper proposes to address this deficiency in the body of knowledge of experiential learning. For example, reflection and feedback from the students is built into the module review process. In the week 12 of the module each student is required to do an assessment of their own contribution to the project. The rationale used for this is based on the lecturer's experience (twenty years as an engineering practitioner) of having to complete end of year reviews. This feedback is important for the lecturer who is continually endeavouring to improve the module content and process year-on-year. The projects undertaken by the class include the following examples: a design brief for a media player case; a wetsuit drying apparatus; development of products using the extensive waste energy and materials from a craft brewery; and developing a bicycle security lock utilising Sigfox Internet of Things technology.

Results and Analysis

A qualitative analysis of results was performed on the interviews-given in the format of structured questionnaires- to the students over a two year period. Qualitative data focuses on words rather than the numbers of quantitative data and there has been a major expansion of qualitative enquiry over the last twenty years (Miles and Huberman 1994). A number of different methods can be adopted to analyse interviews such as "content, narrative and semiotic strategies" (Denzin and Lincoln 2008). Robson (2002) provides the following typology from the work of Crabtree and Miller (1992):

(a) quasi-statistical methods
(b) template approaches
(c) editing approaches; and
(d) immersion approaches.

This follows a progression from a more structured approach to a less formal approach. In fact there is a debate whether the immersion approach can be classified as a scientific method *per se*. The editing approach which is closest to the method employed in this study is characterised by being interpretive and flexible with no or few *a priori* codes. In this method "codes are based on the researcher's interpretation of the meanings or patterns in the texts" (p 458) and it is typified in grounded theory approaches. Charmaz (2004) describes the fundamental premise of grounded theory as letting the "key issues emerge rather than to force them into pre-conceived categories" (p 516). Also the approach in grounded theory is to let the “codes emerge as you study your data” (p 506). Robson (2002 p 59) describes qualitative analysis as being much closer to “codified common sense” than to the “complexities of statistical analysis” associated with quantitative data.

Twenty two responses from the students were analysed in detail covering a two year period. The results using the following four constructs are outlined in table 1: positive aspects, recommendations for improvement, self-rating and needs assessment.

Table 1: Recurrent Themes and Data Patterns

Construct	Results	Analysis
Positive Aspects	Nearly all of the students rated working on a real-life project (design-brief) with a Professional Engineer as the most positive aspect of the project. Also the experience of working in a team was rated very highly.	This result confirmed to the lecturer that the logistics of engaging with an entrepreneur and adopting a structured module roadmap was effective. It also was a motivation for the lecturer. Typically such a project involves a lot of up front work before module commencement.
Recommendations for improvement	The most frequent recommendation was that the project should include the building of a prototype.	Building of prototype has become easier and more cost effective with the development of 3-D printing. Motivation for lecturer to obtain funding for such a facility.
Self-rating	The students were asked to rate their contribution to the project using the following taxonomy: *Exceeded*, *Strongly Achieved*, *Achieved*, *Satisfactory* and *Needs Improvement.*	Results would indicate that in future the lecturer should correlate the self-rating of the student with actual module grades and provide feedback.
Needs Assessment	This has the widest categories of responses with suggestions for training on: presentation skills, time management, market research, project management and research skills,	This variety of the responses to this construct was not unexpected as self-development is very much based on the competence and skills of each student. However this suggests that the lecturer should source some on-line individualised training for students.

Now I will present comments by some of the students gathered during this review process to illustrate the results outlined in the above table. Furthermore this approach allows the voice of the student to be adequately heard as is recommended in the AAU model (Jørgensen 2004).

The first comment acknowledges the amount of effort that is required at the outset to develop the project and the commitment required by the students. However the positive feedback from an external industry based practitioner was very motivating for students.

> *A great deal of effort went into this project and to hear that [the entrepreneur] was impressed with our presentation gave me a great deal of satisfaction and made the project a worthwhile experience. Overall I found that this project helped me gain a great deal of experience in product development and enabled me to improve my skills as an engineer.*

> *It is really helpful and motivating to talk with an experienced professional.*

The real-world scenario was appreciated by the students and working with the entrepreneur challenged them to "up their game". The realisation that their work could have an impact was a source of satisfaction and a realisation that they were now "becoming engineers".

> *This project strongly simulated a real world environment which is exactly what is wanted as a student of engineering.*

> *It was interesting to be part of the process in developing a product that has the potential of being introduced into the real world.*

The process addresses one area that is being increasingly identified as a priority for the education of engineers. Coming up with innovative ideas and technology is only one step. An engineer needs to be able to present and convince that their engineering solution is worthwhile. A product is a lot more complex than just the technology it employs.

> *The presentation is another big positive as we had to present to an actual business person who is really interested in what we have to present. It is very satisfying as a designer to have a person of [the entrepreneur's] ability to come in and be so enthusiastic about your project. [A] Great sense of satisfaction.*

Each team project is assessed and the same mark given to all students in a project team with 10% of the module marks for the presentation and 30% for the business plan. Project assessment criteria involved inter *alia*; the clarity of the presentation; the uniqueness of the solution; the feasibility of the solution and, as it is an engineering module, the level of technical acumen was taken into consideration.

Other factors which are taken into account include and may affect individual student's grade such as: attendance at weekly lecture/lab /team meetings; teamwork and contribution; construction of an artefact (alpha model). A detailed step by step process has been developed that facilitates the learning from this project to be replicated and is reported elsewhere. Figure 1 presents a diagram of the process.

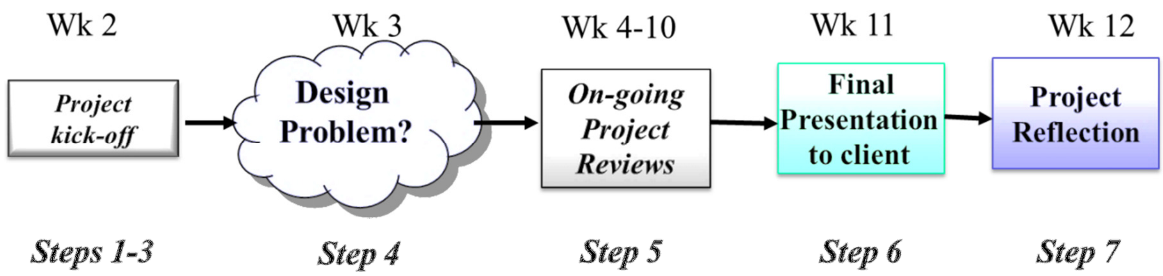

Figure 1: High Level Module Roadmap (Costello 2014)

Work carried out by the students

Now I will briefly describe the process engaged in by the students with their real-life client to emphasise that the methodology simulates an industry based project.

- This design brief is made available to the students via the draft design problem and they prepare for a meeting with the client on the following week. The lecturer meets with the class and presents an overview of the module learning outcomes and the structure of the project as well as assessment criteria and expected project logistics. Then the class is divided into project teams (normally three students per team).
- The class project teams meet the client face-to face. The client presents the design problem to the class verbally with a more detailed description than in the design brief. This provides an opportunity for the class to get a more in-depth view of the client's thinking and to put themselves in the client's shoes (Leonard and Rayport 1997). Also the project teams have time to question the client based on their initial week long research into the problem domain.
- The project teams work on the design problem during the semester using academic and industry standard product design methodologies (Ulrich and Eppinger 2004, Eppinger 2001, Cooper 2001) . The project teams complete a variety of tasks *inter alia*: a detailed project plan in the form of a Gantt chart, market research, customer needs analysis, developing and sketching design concepts, ranking and choosing of the optimum solution. Each week the project teams present a status of their work to the lecturer who in this type of pedagogy acts as a *coach* and *advisor* rather than the conventional lecturing mode.
- Towards the end of the semester the class project teams present their design solutions to the client through oral presentation and a project report. These deliverables include: a set of working drawings, computer-aided design (CAD) models, detailed target specifications, a human factors analysis of the proposed design solution, computer rendering of the proposed design, and an artefact such as a mock-up of the design in cardboard or other materials.

Now I will summarise the conclusions of the study.

5. Conclusions

The purpose of this work is to contribute to the debate on the best pedagogical approach to developing undergraduate mechanical engineering skills to meet the requirements of contemporary complex working environments. The paper provides an example of using student-entrepreneur collaboration in the teaching of modules to Mechanical Engineering final year students. There were a number of learning experiences in this study: by the students; by the lecturer and the industry partner. Additionally, the act of writing of this paper provided a reflective learning experience for the author. The module structure, described here, has embedded entrepreneurial learning in the GMIT department of Mechanical/Industrial Engineering. Working directly with the entrepreneur is a novel pedagogical approach that fosters entrepreneurial thinking and behaviour among the students. Furthermore key stakeholders (in this case the managers and staff of the Innovation Hubs) have been persuaded to engage in the learning process. Both managers have been very supportive of the process as it meets their remit to involve the incubation centres with the main GMIT campus. Reaction to the project was positive as the students appreciated the opportunity to work in a *simulated* environment similar to what they would encounter in industry. Students were particularly pleased that their work might be implemented in a real-world product and not just be archived as another class project. The current literature largely associates simulation-based learning to computer applications such as games. However, this paper disagrees with Chang *et al.* (2008) who identify SBL as solely computer based, and argues that role playing by students interfacing with technology start-ups can also be regarded as “simulation” in a wider sense.

This study is set against the background painted by Gavin (2011) which I will quote here:

> Engineering education is in a state of flux, with universities facing requirements from industry to develop graduates with a wider skills base, while at the same time a revolution in the availability of information is changing the way that students learn (p. 547).

To address this, I propose the concept of *simulation-action learning* (SAL) for engineering students as an enhancement of problem-based learning and the empirical evidence presented in this paper supports this argument. It also contributes to the what Gattieab *et al.* (2011) call the cultivation of engineering education "as a complex system that will prepare students to think critically and make decisions with regard to poorly understood, ill-structured issues" (p. 521) . Finally I argue that this study contributes new insights to the debate on "pedagogies of engagement" (Smith et al. 2005).

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