Exploring ways of enhancing creativity in engineering education to promote innovation: Action research in engineering design

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ABSTRACT

It is widely accepted that creativity is essential and necessary for effectively working in the engineering field. Researchers, academics, educators, engineering organisations and engineering industry representatives all agree that further improvement is necessary in training methods for creativity and innovation in engineering education. The ultimate goal is to have engineering graduates who can think creatively and who can apply their creative abilities to problem-solving. The focus of the research documented in this thesis is to explore ways of enhancing creativity among engineering students and to help them nurture their creative thinking skills during work on the design process in their studies. In addition, the study also aims to help instructors in their teaching approach to enhance students' creative thinking abilities.

This study is based on educational research practice and seeks to address the ways of enhancing creativity in engineering education. Action research was conducted in engineering design units in the Mechanical Engineering Course at Swinburne University of Technology. This intervention focused on ameliorating the creative process in engineering design units with the purpose of getting more creative and innovative product solutions from design projects. This is of particular importance to global manufacturing networks with high labour pay rates such as in Australia, USA and many European countries that have to compete with cheaper offshore markets. Creative engineers are in demand to contribute to the development of innovative product outcomes in a competitive global market.

The research in this thesis shows the challenges in enhancing creativity in engineering education. It was found that the engineering staff's approach affected the creative design process of the students. This approach had been shaped by the instructors' and the engineering discipline's understanding and beliefs about creativity, which needed to be addressed. Another important factor that affected the teaching of creativity were the structural and organisational issues within the engineering discipline.

The data gathered in this study suggests that enhancing creativity in engineering education is not possible until the engineering instructors and those in the engineering

faculty at Swinburne University understand and value creativity practice in an educational context. Three main results drawn from this work are as follows:

- Instructors should understand the practise of creativity in an educational context.
- Instructors need to value creativity as an important part of engineering design.
- The Engineering Discipline needs to value creativity as a core part of the curriculum.

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Yasemin Tekmen-Araci

DECLARATION

This PhD thesis:

- Contains no material which has been accepted for the award to the candidate of any other degree or diploma, except where due reference is made in the text of the examinable outcome
- To the best of the candidate's knowledge contains no material previously published or written by another person except where due reference is made in the text of the examinable outcome
- Discloses the relative contributions of the respective workers or authors where the work is based on joint research or publications

Editorial assistance:

- Peter Haffenden. Inherit Earth Australia.
- Has edited this thesis simply for grammar, spelling and basic smoothing of the language used in the presentation of the ideas expressed. Mr. Haffenden's background is in journalism and is not in the engineering profession nor is he in any way familiar with the engineering education.

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PUBLICATION LIST

The following papers represent findings and outcomes from this research which were published during the research in conferences and journals.

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

LIST OF APPENDICES

1 CHAPTER ONE: INTRODUCTION

1.1 STUDY CONTEXT AND IDENTIFYING THE RESEARCH GAP

Many researchers, starting from Guilford in the 1950s, Amabile in the 1980s, de Bono in the 1990s, Cropley in the 2000s and continuing to Lin in the 2010s argue that education has a role to play in relation to creativity. Creativity is not simply a gift given to a select few – it is something that can be learned and taught (Cropley & Cropley 1998; Fry, 2006; Lin, 2011; Runco, 2004; Stouffer, Russel, & Olivia, 2004; Williams, Ostwald, & Askland, 2010).

Engineering needs both technical knowledge and creative skills (Mokhtar & Duesing, 2008). However, teaching creativity to engineering students can be challenging (de Vere, 2009), as engineering students are argued to have cognitive hindrances, such as a lack of design process knowledge and imagination (Zemke & Zemke, 2013). There is a consensus among researchers (Baillie & Walker, 1998; Churches & Magin, 2001; de Vere, Kuys, & Melles, 2010a; Kazerounian & Foley, 2007; Pappas, 2002; Williams et al., 2010; Zhou, 2012a) that fostering creativity and creative thinking is still an issue to be studied in engineering courses.

A large majority of the researchers highlight the need for re-structuring undergraduate engineering education courses to make creativity a core part of these courses (Cropley & Cropley, 2000; de Vere, 2009; Panthalookaran, 2011a; Pappas, 2002; Santamarina, 2003; Zhou, 2012b). The majority of the studies (Charyton & Merrill, 2009; Kazerounian & Foley, 2007; Mitchell, 1998; Stouffer et al., 2004) have a holistic approach and argue that creativity and creative thinking should not only be integrated in the units but be inherently a part of the whole engineering curricula.

The literature suggests that the best option is to teach creative thinking skills during the problem-solving processes (Churches & Magin, 2001; de Vere et al., 2010a; Kazerounian & Foley, 2007; Santamarina, 2003; Williams et al., 2010). Generally, the studies link creativity with design education (Pappas, 2002) and suggest that engineering faculties should see design pedagogy as a model and potential for fostering creativity (de Vere, 2009; Cropley & Cropley, 2000).

There have been a number of studies to address enhancing creativity in engineering education (Baillie, 1998; Burton & White, 1999; Churches & Magin, 2001; Cropley & Cropley, 2009; Dym, Agogino, Eris, Frey, & Leifer, 2005). Within the framework of creativity issues, critical gaps have been identified in the literature. Early works show that the issue of creativity has only been addressed in certain specialised areas of the engineering discipline.

However, none of these approaches were experimented with in other areas of engineering curricula. It would benefit the study of creativity in engineering to explore similar fields of engineering to the one already studied (Daly, Mosyjowski, & Seifert, 2014; de Vere, 2013; de Vere, Melles, & Kapoor, 2010b; Pierrakos, Pappas, Kander, & Prins, 2008). de Vere, in his PhD thesis awarded in 2013, investigated critical areas in engineering education and put forward the impact and relevance of Product Design Engineering (PDE) pedagogy as an answer to the current educational expectations of engineering regulatory organisations. Much of the research up until now has been descriptive in nature, by comparing two other engineering disciplines, but no previous study has been used to gain benefit from using one engineering discipline as a benchmark for another.

The relationship between instructor effort and creativity training has been widely investigated. Many researchers believe that the educators are responsible for stimulating creative thinking among students and to find the balance between theoretical and creative subjects (Kazerounian & Foley, 2007; Richards, 1998). However, instructors' teaching practices are shaped by their beliefs. Some of these beliefs need to change for teaching of creativity. This change process involves encouraging educators to develop new teaching methods (Henderson, Beach, & Finkelstein, 2011; van Driel, Bulte, & Verloop, 2007). Many academics applied different methods to integrate creativity during problem-solving in engineering education, which is summarised in Chapter Two. The results showed progress in terms of creative thinking with most methods. However, helping the engineering instructors in their teaching or identifying the challenges of working in collaboration with engineering instructors in teaching of creativity remain relatively neglected areas of research.

A large and growing body of literature suggests how instructors need to behave in class (Ghosh, 1993; Goldschmidt, Hochman, & Dafni, 2010; Liu & Schonwetter, 2004; Törnkvist, 1998; Zhou, 2012b;), how the assessment criteria should be prepared for having a fruitful creative process (Berglund, Daniels, Hedenborg, & Tengstrand, 1998; Daly et al., 2014; Froyd, Wankat, & Smith, 2012; Takai, 2011; Williams et al., 2010) or how the role of the supportive environment affects creative learning (Abdekhodaee & Steele, 2012; Meyers & Ernst, 1995; Felder, 1988; Goldschmidt et al., 2010). However, much uncertainty still exists about the interrelations of the instructor approach, the environment, the creative tools and/or the assessment process in the field of learning and teaching creativity. There have been several attempts to make creativity a part of the engineering education by conducting different methods. However, little research exists that explores ways of enhancing creativity in engineering curricula with a holistic perspective. To the best of the author's knowledge no research has been found so far using 'action research' in an engineering education context, that has first identified and described the creativity issues in the learning and teaching environment, then developed and implemented an intervention to remedy these issues.

As Cropley (2015b) lately clarified, there is a disconnection between engineering and creativity and innovation which needs to be addressed holistically. The research in this thesis investigates creative pedagogy in engineering from the perspective of these three aspects (Lin, 2011; Zhou, 2012a):

- "Creative teaching" focuses on teacher practices, their approach towards student learning.
- "Creative learning" focuses on students' learning approach.
- "Teaching for creativity" focuses on the methods and ways of teaching for the development of creative abilities.

All data was collected for this study by considering these three areas.

1.1.1 Definition of terms

The definition of some terminology used in the study is given below:

While a variety of descriptions of the term 'creativity' have been suggested, this research will use its own definition compiled from many others (Amabile, 1983; Casakin, 2007; Cropley & Cropley, 2010a; Kazerounian & Foley, 2007; Runco; 2007; Stouffer et al., 2004; Thompson & Lordan, 1999; Williams et al., 2010):

Creativity empowers the engineer with ingenuity to tolerate the unconventional so as to generate original and non-obvious alternatives, which ultimately lead to better, innovative and worthwhile solutions to design problems.

This study also overviewed the many definitions of creative thinking (Cross, 2008; de Bono, 1995; Ibrahim, 2002; Treffinger, Isaksen, & Stead-Dorval, 2000) and concluded that it is a thinking process which enables the engineer to solve design problems by generating a variety of alternatives. The aim should be to achieve an optimal outcome which is a variable innovation on what currently exists. The study accepts the argument of Howard, Culley, & Dekoninck (2008, p. 160) indicating that "without creativity in design, there is no potential for innovation". The definitions adopted here will determine the factors that will be considered in the study.

Throughout this research, the terms given below are defined as they are used in Australian higher education system, to prevent any misunderstandings with other terminology.

Course	: The entire program of studies offered to complete a university degree.
Unit/Subject	: A unit of teaching that generally lasts one academic semester.
Instructor	: Higher education level lecturer or tutor.

1.2 RESEARCH QUESTIONS AND STATEMENT OF PURPOSE

The main research questions in this study are:

- How to enhance creativity and creative thinking in student engineering?
- How to teach creativity and creative thinking in engineering education in an effective and efficient way?

There are also sub questions, which describe the current situation and help to answer the main question:

- What are the challenges related to embedding creativity in engineering curricula through engineering design subjects and what needs to be done to remedy these deficiencies?

- What are the most effective approaches for teaching creativity in engineering curricula?

- What aspects of teaching creativity are used in Product Design Engineering education programs that could be transferred to the more traditional fields of Mechanical Engineering?

The aim of this research is to examine and explore ways of fostering creativity, nurturing creative thinking skills and developing a framework for implementing the findings into engineering curricula during problem-solving processes in engineering design. The research will be carried out using 'qualitative' methods of study. The major focus of this qualitative study is to identify the creativity issues in engineering education first and then to help the instructors in their teaching approach to enhance students' creative thinking abilities by using Action Research methodology. The purpose of this study in the long term is to enhance engineers' creative thinking skills in general. However, in the framework of this research, the focus will be on engineering design units, as it is accepted that creativity is linked with design.

Within this context, this study will critically examine the creativity issues in the Mechanical Engineering (ME) curriculum at Swinburne University of Technology in Australia by focusing on engineering design units in this course: Mechanical Systems Design and Machine Design. The initial aim of this investigation is to identify the creativity problems in ME design subjects in order to teach creativity in an effective way through observations, analysing the relevant literature and leveraging design pedagogy in PDE. The problems will clearly be diagnosed and students will be supported in their designing and learning approaches. It is worth clarifying that the study is not investigating how to develop engineers' design skills. This has already been done with the emergence of the PDE course by implementing more design subjects in the engineering curricula that use engineering theories in a product design scenario.

The goal of this research is to explore ways of enhancing creativity and creative thinking among ME students by using PDE pedagogy which has not been investigated by prior researchers. The role of the author during the Action Research involves supporting the instructors. Consequently, the author aims to work collaboratively with engineering instructors to teach creativity and creative thinking in an efficient and effective way.

1.3 JUSTIFICATION OF THE STUDY

In modern civilisation creativity and innovation are major driving forces for sustainable economic growth and competitive achievements (Badran, 2007). Engineers' contribution to new product development would be limited without a creative methodology. In order to get more innovative results from engineers, creativity should be fostered throughout the engineering education curricula (de Vere, 2013).

A wide variety of research can (and must) be undertaken to improve on creativity issues in engineering education. However, this research has been structured by considering the 3-year duration of the PhD, the author's interest and perspective, the context that she has been involved in and the university where the research has been conducted. This section justifies the approach to be taken in the study.

Different researchers highlight the importance of different aspects of creativity, focusing on the 4Ps of Rhodes (1961), such as the Person (Cropley & Cropley, 2010a; Piirto, 2011), the Product (Sternberg & Lubart, 1996), the Process (Hasirci & Demirkan, 2007) and the Press (Sternberg, 2006). The literature argues the importance of each aspect, from different perspectives. For this reason, a holistic approach is a must in studying creativity. In the context of this research it has been accepted that person, product, process and press (environment) are all-important factors affecting creativity. The study will focus on the 'process', but will not be isolated from the other Ps. Because there is not enough time to observe the changes in personality in the duration of a 3-year PhD thesis and it is much harder to change personal attributes in such a short time. Daly et al. (2014) also explained that personal properties do not change much over a short period of time and are not likely to change during only a term long subject. Therefore, the study does not test students' creativity with pre and post evaluations. Although it is expected that a person will show changes in his ideas, activities or approaches after participating in a creative process. Product, on the other hand, is a solid outcome of a creative process and it can also give clues about the creative process. Engineering designers — by turning the ideas in their minds into an artefact — learn a lot during the design process of problem-solving (Ferguson, 1993). For this reason, the efficiency of the creative process during a design progression exercise is believed to be an important indicator for final creative outputs. As a matter of fact, experiencing a creative process is expected to better enable designing of creative products and coming up with solutions to problems. However, a comparative investigation of the products was not thoroughly done due to the limited time and therefore was not included in this study.

Although some researchers, such as de Bono (1990), claimed that teaching creativity separately from regular subjects gives a better result this study focuses on conducting research on integrating creativity within engineering design units and not being separate from the engineering curriculum. If the results of this research are expected to be implemented in the future, it will be more practical to change some aspects within the existing subjects rather than creating time for a totally new subject in the already tight curriculum. There are also other reasons why teaching creativity separately is not preferred. One disadvantage of teaching creativity and creative thinking separately in the curriculum is that it might take a longer time for its effects to show up and it might be harder to evaluate its effect. The effects might be evident in future units or in a totally different context, like a student's private life and activities where it will not be seen, and it will be harder to know how the taught materials influenced their educational practices. It is not that creativity should not be taught separately, because it can be taught and it might nurture positive effects. However, the duration of a PhD will not allow seeing the effects in a broader perspective in an extensive time frame.

It is suggested by the researchers (Churches & Magin, 2001; Liebman, 1989) that capstone design subjects, with their focus on a multi-dimensional approach to a topic, are not enough to make up for the lack of creativity in engineering education, but due to the tight course program it is not easy to add more units (Wulf, 2000; Lumsdaine &

Lumsdaine, 1995). So this study explores ways of enhancing creativity in the current course programs, but in a practical way that can be easily and effectively adopted. The reason for conducting the study within the framework of mechanical engineering (ME) design subjects is that first of all it is accepted that creativity is inherently linked to design. Secondly, a large majority of researchers (Eekels, 1987; Liu & Schonwetter, 2004; Santamarina, 2003; Zhou, 2012a, 2012c) link creativity and innovation with "Problem Based Learning" that is a feature of ME design projects.

Another issue is deciding in which year in a 4-year engineering curricula to focus on enhancing creativity. A considerable number of studies emphasise focusing on first year engineering education to expose students to more design activities. This would set an environment for creative thinking early in a course. However, this study focuses on 3rd and 4th year current ME design units at Swinburne University of Technology. The reason for choosing these units is that they are the only engineering design units in ME and we are looking at creativity in the context of design. Moreover, they both have a problem-solving focus in their content, which is supported by many researchers as a suitable venue for fostering creativity (de Vere, 2009; de Vere et al., 2010a; Dym, Agogino, Eris, Frey, & Leifer, 2005; Stouffer et al., 2004; Treffinger, Young, Selby, & Shepardson, 2002).

Lastly, Product Design Engineering (PDE) is an engineering discipline having multidisciplinary curricula and structure (de Vere, 2013). It can be used as a model for fostering creativity in other engineering disciplines (de Vere, 2009). For these reasons, it is assumed that PDE would give some clues in promoting and enhancing creativity in ME to pursue this study.

1.4 SIGNIFICANCE OF THE RESEARCH / CONTRIBUTION

There are several important areas where this study makes an original contribution to creativity issues in undergraduate engineering education. As the vision of Swinburne University of Technology (2015) is "to become Australia's leading university of science, technology and innovation by 2020", creativity and innovation are highly emphasised in the current engineering curriculum.

There has been an increase in the discussion of the importance and necessity of creativity and creative thinking in engineering education. Nevertheless, creativity has not become an inherent part of engineering curricula in most parts of the world like it is in art or design. Therefore, this study is an important step, with a holistic approach, in suggesting creativity and creative thinking be inherent and integral parts of every engineering curriculum. Even though creativity issues concern all fields of engineering, this dissertation specifically explores ways of integrating creativity in engineering design processes that took place in the ME course – with an expectation that the research can be used as an exemplar for other engineering disciplines to learn from.

In recent years, there has been an increasing interest in PDE, which is still a new concept for most universities that have an engineering and/or design school. What makes this study unique is the method of taking the relatively newly designed PDE course as a model for integrating creativity into an older, more traditional engineering course such as mechanical engineering (ME). It creates new knowledge in the field of gaining an understanding of how creativity occurs in PDE, which will then be used as a benchmark to enhance creative skills among mechanical engineering students.

As a result, this study makes a major contribution to research on creativity. First by pointing out the issues around the introduction of creativity and creative thinking in engineering design units. These are typical ME design subjects occurring around Australia and in US universities. Then the study continues with the introduction of an action plan, including learning tools, materials, patterns of communication and environmental intervention plans, to implement in the design subject and which aims to remedy these identified issues around introducing creativity.

The majority of the researchers involved in implementing creativity in engineering education are engineering faculty members who teach engineering subjects. The fact that the author is coming from an industrial design background is believed to bring a different perspective to the setting up of the research plan. This study provides an important opportunity to advance our knowledge of a "designer-in-residence" (Churches & Magin, 2001) concept in an engineering context. Richards (1998) believes that the educators are responsible for stimulating creative thinking among students and the ideal arrangement would be that full-time academics who have experience in design should teach design subjects (Churches & Magin, 2001). Even though the actions were planned by the author, who has a design background, engineering design units continued to be delivered by engineering instructors. In this respect, this study is a vast step in developing engineering instructors' ways of teaching by being a collaborative interdisciplinary research study.

Previous studies were mostly focused on implementing methods and their results about fostering creativity in engineering education. However, the challenges of enhancing creativity in engineering has been a neglected area of study. In this respect, the present study makes noteworthy contributions to the understanding of the challenges and barriers of enhancing creativity in engineering education and in identifying the reasons for these barriers.

If the underlying reasons for the challenges faced were not questioned and explained, enhancing creativity in engineering education would not be thoroughly explored. This new contribution to knowledge is of significant benefit to engineering faculties that are reviewing their curriculum in order to enhance more creativity and innovation in engineering education in order to meet the 21st century's expectations of more creative engineers.

The results of this study will provide insights to engineering educators and academic researchers who are seeking ways of enhancing creativity in engineering education. The dissertation results hope to provide knowledge for similar future studies in different engineering courses.

1.5 METHODOLOGY

The study undertakes a qualitative investigation into the enhancement of creativity in engineering education. The research is conducted in stages:

1. Exploration of the current situation of creativity in ME and PDE

2. Action research in ME design units

- Phase 1: Machine Design
- Phase 2: Mechanical Systems Design

The initial stage will compare the classroom practices, the approach and understanding of both students and instructors in relation to the creative process and creativity during problem-solving processes in ME and PDE. The collected data of Stage 1 is reviewed and evaluated in order to clarify the current creativity issues in ME and to identify the processes that can be transferred from PDE to ME for enhancing creativity. In the light of this evaluation, a series of actions are planned.

Improving education is a cultural action (Kemmis & McTaggart, 1988) and different cultural actions can conflict with each other (Schein, 1984). This study involves understanding the phenomenon from the students' and the instructors' perspectives in two different courses, PDE and ME. Soft System Methodology (SSM) was the preferred process to analyse these perspectives. This system helps to understand how people create the meaning of their experiences in complex organisational situations and how to evaluate plural views and values (Checkland, 2000; Maqsood et al., 2001; Molineux & Haslett, 2003).

The second stage involves the Action Research process in two engineering design units. Action research methodology is highly preferred in the area of curriculum review and development in the Australian education context (Kemmis & McTaggart, 1988). First a problem situation is diagnosed, then remedial action is planned and implemented and the effects are monitored (Burns, 1997). The cycle of Action Research recommended by many researchers (Cherry, 1999; Ferrance, 2000; Kemmis & McTaggart, 1988; Kemmis, McTaggart, & Nixon, 2014) is "planning, acting, observing, and reflecting". So, the action plan was continually modified according to the observations during the classes by initially identifying the problem, clarifying the nature of the problem, checking the literature, then deciding an action plan, implementing it and interpreting the data.

The first Action Research phase focuses more on the students, about teaching them creativity. However, the second Action Research phase is more about the instructors' way of teaching and understanding the underlying reasons for the issues that occur during the exercise of enhancing creativity. However, these two phases should be seen as a whole, as the majority of the participants are the same and the two design units are two consecutive units.

The main data collection methods are observations, interviews, regular meetings with instructors and surveys. All the research stages, the methodology and data collection methods are further explained in detail in Chapter Three.

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the National Statement on Ethical Conduct in Human Research. Ethics approvals have been taken in steps:

- SHR Project 2014/200 (04/08/2014 - 01/03/2018).
- SHR Project 2014/255 (06/11/2014 - 30/04/2018).

I verify that all conditions pertaining to the ethics clearance have been properly met with respect to informed consent and secure data use, retention and disposal.

1.6 GENERAL LIMITATIONS

There are some limitations of the transferability of the study results. The reader should bear in mind that this study provides findings from a specific context. It provides clues about how to enhance creativity in certain circumstances but it does not offer a method that can be applied in all situations. Rather, the thesis seeks to provide insight into how to enhance creativity in ongoing engineering curricula at Swinburne University. Conclusions drawn from the Action Research in this study do not necessarily apply directly to every engineering design subject in another university, but these conclusions do highlight certain points which can be applied in similar situations.

Because the study accepts that creativity can better be enhanced during the design process, the boundaries of this study are limited by the nature of the current ME design units at Swinburne University of Technology. Due to practical constraints this research cannot provide a comprehensive review of a newly designed creativity focused subject for the engineering curriculum. However, it does provide solutions within the current ongoing engineering design subjects in ME and outlines the barriers to creativity teaching. The findings are highly dependent on the data sources; in this case the instructors of the studied subjects and the students who have been taking these units. The findings might show change if any of the circumstances change, such as the studied course or the university, the cohort of students or the instructors, or the nature of the design problems. These defined challenges can be addressed in similar or different circumstances in further research.

It is beyond the scope of this study to examine instances of creativity other than those observed and identified within class hours. Observations took place in lecture and tutorial hours, however the author also tried to understand the occurrence of the creative process outside the class by conducting in-depth interviews. Nevertheless, the idea generation process in which the creative occurrences mostly happen was not possible to wholly observe. Sometimes they happened outside the class hours or happened unconsciously, which made them difficult to identify. In these cases the study is limited to the answers taken from the participants through the surveys and the interviews.

These studies might be repeated in the following years to observe and ensure the validity and reliability of the findings. However, the PhD duration does not allow such a longitudinal study.

1.7 RESERACHER'S PERSPECTIVE

The author's main reason for choosing this topic is personal interest. Having studied one year of Engineering at Middle East Technical University, I realised that engineering had limited creativity in it. I thought that way then when I was a student in 1997. So I decided to study a course in which I could think creatively and bring innovative solutions to given problems, and I changed my major to Industrial Design at the same university. This change played a significant difference in my life. Even though I am extremely happy with being an industrial designer, I have been still questioning why, as a student back then, I thought engineering did not allow any creativity. There must be something missing in the curricula or in the way the subjects were delivered. In addition to that, I have been married to an engineer for eight years, which also gave me the urge to question and to discuss many of my concerns with my husband about engineers, engineering education and what needs to be done.

It is important to acknowledge that much of the inspiration and motivation for this work derived from my working experience as a "Creative Design Lecturer" at the German

University of Technology in Oman between 2010 and 2012. This unit was being taken by all the disciplines in the university as a compulsory subject. I had worked in preparing the studio based assignments specific for different disciplines and I became responsible for the development of the Creative Design unit content for engineering. Even though I was teaching the first year of engineering students, most of them were opposed to doing creative design exercises, because they had the misbelief that 'engineers think analytically and critically but not creatively'. It had been a challenge for me to come up with appropriate methods that would help engineering students in their future studies.

Furthermore, before commencing my PhD studies, I attended the 2nd International Conference on Creativity and Innovation in Design, Desire11 Conference in Eindhoven University of Technology in 2011. My colleague and I conducted a workshop during the conference, "Two Innovative Methods for the Creative Design Process: See With Your Eyes Closed and Collective Association". I experimented with two different creativity-stimulating methods with the participants, which encouraged me to explore more ways of enhancing creativity in education.

When studying organisational culture, as in this study, Schein (1984) stated that if the investigator is from the same culture as the organisation that is being investigated, the perceptions, thoughts and feelings will not be very different. Therefore, I believe with my designer and design educator background I contributed in a different way from the engineering researchers to the creativity in engineering education research field.

1.8 STRUCTURE OF THE THESIS

The outline of the thesis is as follows:

Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Methodology

Chapter 4: Exploration of the current situation of creativity in ME and PDE

Chapter 5: Action Research in ME design units

Chapter 6: Results/Findings

Chapter 7: Discussion and Conclusion

The overall structure of the thesis takes the form of seven chapters, including this introductory chapter. The central question in this dissertation asks how creativity and creative thinking can best be enhanced in engineering education. In order to prepare the context of this study, I initially reviewed the relevant literature to expand my knowledge in the field. Chapter Two begins by laying out the theoretical dimensions of the research. The issues in engineering education were highlighted. The necessity and benefits of creativity and innovation in engineering education have been clarified. Design as a unit in engineering education was described. Challenges of design teaching were examined in an engineering education context. Then, creativity and innovation in an engineering context were investigated. Finally, creativity pedagogy in engineering education was discussed. Similar implementations from previous research have been analysed and means of creativity tools and assessment methods have been reviewed.

The third chapter is concerned with the methodology used for this study. It clarifies the study stages and the preferred research methods. It gives details about the cohort of participants recruited for the study. It provides examples of the relevant materials that will help to understand the study context such as the unit outlines, rubrics, survey and interview questions.

The fourth chapter presents the findings of the comparative study between ME and PDE. The creativity issues in the engineering curriculum were identified. The study had a qualitative approach and used interpretations to find out the creativity aspects used in the multidisciplinary PDE curriculum that could be transferred to the ME curriculum to enhance creativity among engineering students. In this chapter, many visualisations (graphics) were used in order to help the reader to better understand the situation.

The study then goes on in the fifth chapter to explain the Action Research processes and the results gained from studying two different engineering design units: Machine Design and Mechanical Systems Design. Several actions were designed and implemented in the units in collaboration with the engineering instructors. All of these processes were observed and reflected on. Then new plans were designed and enacted. Throughout this Action Research many issues were raised about promoting creativity in an ME context that needed further analysis. After conducting the comparative study between PDE and ME, and Action Research in ME, the study focuses on describing the challenges of enhancing creativity in engineering design education and overcoming these barriers to introducing creativity.

So far, the thesis presented the outcomes and the findings from each stage. Chapter Six synthesises the outcomes from these studies to identify the broader results. In order to have a deeper understanding of challenges to enhancing creativity in engineering education the underlying reasons for these challenges were investigated. This chapter presents the overall findings under three main themes:

- Engineering staff approaches in enhancing creativity
- Instructors' understanding and beliefs about creativity
- Structural and organisational issues within engineering

The final chapter, Chapter Seven, draws upon the entire thesis and includes a discussion of the implication of the findings to future research into this area. The conclusion gives a brief summary and a critique of the findings. The study finishes by describing the main changes that need to be carried out for enhancing creativity in engineering education.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 ISSUES IN ENGINEERING EDUCATION

This section initially explains the definition, meaning and nature of engineering and its distinction from other disciplines. It gives an overview of the shifts and developments in engineering education through history to better clarify where it is now. Then it further clarifies the issues and challenges in current engineering curriculums, highlighting those related to creativity as an element of teaching. The chapter continues with analysing the curriculum reforms carried out by engineering and educational organisations and institutions.

Engineering education has a long history and there have been many issues to be considered. However, the focus of this study is on ‘creativity’ issues in the engineering curricula. Many engineering programs struggle to enhance creativity in their courses.

This section serves to introduce the research on creativity in engineering education into the current issues in engineering education and helps in better understanding the requirements that need to be addressed to enhance creativity and creative thinking in engineering curricula. This is important because the global manufacturing networks that have high labour rates, such as Australia, need to compete with cheaper offshore market rates. This is made possible by educating creative engineers to contribute to the development of innovative product outcomes in a competitive global market.

2.1.1 Definition and Nature of Engineering

Engineering is one of the most extensive and complex systems in the world (Rugarcia, Felder, Woods, & Stice, 2000). It has a large number of elements and a large number of relationships among those elements. In order to understand the complexity of engineering, first it is important to consider the description of it (Zhou, 2012a).

The word “engineering” is etymologically derived from the Latin word “ingenium”, which is also the root of “ingenious”. The Oxford Dictionary of English (2014) defines ‘engineering’ as “the branch of science and technology concerned with the design, building, and use of engines, machines, and structures”. The US Accreditation Board for Engineering and Technology (ABET) (2015) defines engineering as “the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize economically, the materials and forces of nature for the benefit of mankind". Engineers Australia (2014) — the accreditation body for Australian engineering programs — outlines the major role of the engineer as "the creation of national well-being and security through the design and implementation of products, processes and technical systems of broad social utility". Petroski (1996) describes engineering as "the art of rearranging the materials and forces of nature" (p. 1) and as "a fundamental human process that has been practiced from the earliest days of civilization" (p. 2).

The application of science and mathematics is widely accepted in the engineering field. Engineering needs to apply these skills to address problems, which brings about the concept of design (Ghosh, 1993). Engineering refers to arranging the design and production of systems and products (Vincenti, 1990). Cropley (2015a) defines engineering as "the design and development of technological solutions to problems" (p. 2). There is a belief that anybody can do a design, but it is the engineers who establish procedures and build things (Kazerounian & Foley, 2007). The engineering profession expects engineers to recognise, validate and solve problems on their own or through team work (Liu & Schonwetter, 2004). Engineering is the ability of solving problems with a creative process (Zhou, 2012a) and "designing a novel artefact" (Daly et al., 2014, p. 417).

According to Vincenti (1990), engineering needs to be grounded on factual knowledge; it needs appropriate theoretical tools. Engineers need to know "certain concrete things" to apply and to construct designs. Vincenti (1990, p. 205) thinks engineering is a "quantitative activity". However, after reviewing the cognitive design research literature, Visser (2009) argues that engineers both use quantitative methods such as analysis and calculations and qualitative methods like conceptualising and reasoning. Vincenti (1990) makes and analytical study and describes the evolution and the development of engineering knowledge based on the changing requirements of engineering designers. He sees problem-solving and design as almost the same in an engineering context. Visser (2009) believes that the solution always depends on the knowledge. Everything required is available in the textbooks (Visser, 2009). However, Vincenti (1990, p. 220) argues that the skills must be learned through practice and the skills are "what separates an outstanding designer from an ordinary one". Ferguson (1993) argues that engineering designers use not only science for knowledge, but also their knowledge based on their experiences and empirical observations. Hubka and Eder (2003) mention the importance of experience and state that ten years is required for an engineering designer to be fully competent.

"Engineers, and engineering, are concerned fundamentally with the application of knowledge and skills to solve problems. Those solutions typically take the form of tangible artefacts (products), more complex arrangements of physical elements (systems), ways of doing things (processes), or other intangible, value-adding solutions (services)" (Cropley, 2015a, p. 63). Putting forward the difference of engineering from other disciplines also helps to better understand its position.

2.1.2 Difference of Engineering from Other Disciplines

Engineering has many differences from other disciplines like design, art or science, as well as having many similarities.

Gold (2007) argues that engineering is the oldest field or discipline among art, science and design. He distinguishes science from engineering by stating that "science is a hat of laws, engineering is a hat of violations" (p. 26). However, engineering and design both work from "need and desire" (p. 25). Ferguson (1993) argues that even though the job of an artist and an engineer both start with drawings on a blank paper by transferring the vision in their minds, engineers are not happy to be called artists, because art lacks the rigor of science. Vincenti (1990) puts the difference of engineering this way: Scientists search for understanding; they do not have rigid goals. However, engineers have very concrete objectives and they depend on design criteria and specifications. Akin (2001) compares architecture and engineering, saying architects behave depending on their hearts and take risks, while engineers are not allowed to make mistakes.

Engineers Australia (2014) confirms design, involving imagination, struggle and compromise as the "essential discipline of the engineer" as it "distinguishes engineering from science and mathematics". Lawson (2006) states that during problem-solving, scientists analyse and focus on problems, whereas designers synthesise and focus on solutions.

Sheppard and Jenison (1996a) see the primary focus of engineering design as an artefact, whereas design education focuses on the students in helping them understand and experience the process of realising an artefact. The quality of the artefact has a secondary importance (Sheppard & Jenison, 1996b). Depending on the same protocol studies, researchers agree that engineers are more performance driven and product focused, whereas designers are innovation driven and process focused (Mann & Tekmen-Araci, 2014; Lande & Oplinger, 2014; Goldschmidt, Casakin, Avidan, & Ronen, 2014).

Artists are looking inwards when creating artefacts and the aesthetic is important for them. Industrial designers, on the other hand, are problem solvers like engineers. Nevertheless, they have the tendency and flexibility to behave intuitively like artists during the problem-solving process. However, engineers rely on scientific facts during problem-solving. An artist's artefact does not need to satisfy a human need, whereas a design artefact needs to take into account the aesthetic, ergonomics and the function of an object; furthermore, it may also reflect the designer's emotions. A design problem can be solved in many different ways so the artefacts for the same kind of problem might be all different from each other. An engineering artefact, on the other hand, has constraints and limitations and the initial aim of an engineering artefact is to be functional. A 'design engineer' is in between though. S/he must apply scientific rules of engineering, but also needs to incorporate his/her approach with design thinking. S/he has the flexibility to frame the problem in order to create alternative solutions.

How engineering students distinguish themselves from other students is also interesting. Stevens et al. (2007) conducted an ethnographic study with undergraduate engineering students for four years in an US university. They (2007) found that students choose engineering because they believe they will make good money and comfortable life. Students justify their comfortable future by having more difficult school work than other students. The "meritocracy of difficulty" belief helps engineering students to distinguish themselves from other students by seeing their discipline in a superior position. A person "is worthy of engineering only if one is willing to work extraordinarily hard and to sacrifice experiences and basic pleasures that are ordinary to other college students (Stevenes et al., 2007, p. 8).

2.1.3 Shifts in the History of Engineering Education

There have been major shifts in engineering education over the past one hundred years (Froyd et al., 2012). Most engineering education has traditionally had a theory-based curriculum (de Vere et al., 2010a; Cropley & Cropley, 1998; Siu, 2012). Unlike for today's engineers, early engineering education did not involve "applied science". It was the "art of doing what worked". Then, as technology developed, scientific issues were raised and became more important (Liebman, 1989).

The first major shift that affected the curricula occurred between 1935 and 1965, moving from a hands-on practice based approach to a more science and theory based style (Froyd et al., 2012; Prados, 1998; Sheppard & Jenison 1996a).

The concept of creativity first appeared in engineering in the 1950s and it was used to describe the ability "to synthesize new ideas from a combination of past and present experience" (Ferguson, 1993, p. 57). The launch of satellite 'Sputnik 1' by the Soviet Union accelerated the link between creativity and education (Froyd et al., 2012; Cropley, 2015a) and it was a shock for Western countries. They faced the failure of their engineers and they realised that the reason for this failure was the lack of creativity. Therefore, there were policy changes in education in the United States to overcome the shortcomings of a lack of perceived creativity (Cropley & Cropley, 1998; Froyd et al., 2012; Shaheen, 2010). Since World War II, engineering has begun to be taught as an applied science, unlike its prior presentation as a mixture of design and scientific analysis (Ferguson, 1993). This transition was unavoidable because of the direction of the modern world. "The knowledge explosion has forced the teaching of more basic principles because that is a more efficient way to convey a large amount of information" (Liebman, 1989, p. 262). Engineers need to understand a wide variety of materials, behaviours and techniques and this can only be done by that approach. In the meantime, some things were lost; there was little time left for practice. Following that creativity was encouraged in many engineering schools all over the world, especially in the first educational year to make engineering fun and to attract students (Ferguson, 1993).

The second shift again came from the United States. In the late 1950s and early 1960s engineering education emphasized “learning by doing” (Kazerounian & Foley, 2007, p. 761). However, in the 1970s and early 1980s the influence of the space race, energy crisis, nuclear developments, the cold war and the use of computers shaped engineering education. Consequently, engineers begun to be trained like scientists (Kazerounian & Foley, 2007); engineering science and theory in the curriculum was increased with the aim of helping engineering students better understand complex principles (Dutson, Todd, Magleby, & Sorensen, 1997). From the 1970s connections between creativity and engineering were lost and engineers didn’t prioritise creativity. There was another factor, which negatively affected the re-connection again, the link of creativity to the art domain in the public’s eye (Cropley, 2015).

The third shift was the focus on engineering design. The previous shift left graduates having less experience in engineering practice (Liebman, 1989) because the emphasis on science and mathematics had gone beyond what was actually needed (Froyd et al., 2012; Sheppard & Jenison, 1997). After engineering educators complained about the lack of the design understanding of students, educators recommended incorporating design throughout the four-year curriculum (Sheppard & Jenison, 1996a). Senior level design units were developed with the hope to bring the practical side back to engineering (Dutson et al., 1997; Froyd et al., 2012). A further step was the implementation of “first year design” units (Dym et al, 2005; Sheppard & Jenison, 1997), which became common in the US Accreditation Board for Engineering and Technology (ABET) accredited institutions in the 1970s and 1980s. Then educators renewed the engineering curricula to strengthen the “design component”, initially in the United States and in Europe and then in other places (Kazerounian & Foley, 2007).

The next shift was the move to continuous research in education and learning areas in engineering education. Student involvement in learning, cooperative learning, interdisciplinary curricula and alternative assessments are some of the issues addressed (Froyd et al., 2012). The last major shift has been happening in conjunction with changing technology methods in delivering lectures. There have been several technological applications, like using TV, videotape or internet for delivery or using classrooms with networked PCs. Another improvement is getting individualised student feedbacks or using personal response systems which encourage student involvement and lead to a transformation to a more student-oriented pedagogy (Froyd et al., 2012). The changing technology methods bring alternative ways of teaching and learning.

Because of these changes in engineering education history, there has been a transition in curriculum delivery from practice to theory. When the focus was on more science-based projects instead of applied activities the emphasis on creative thinking decreased. Even the belief in the necessity of the 'creative engineer' has disappeared. The engineering industry has shown deficiencies in the working world with the practical application of theoretical knowledge. Changes in education have been made by integrating design units into curricula with the aim of eliminating this deficiency. However, these changes did not necessarily solve creativity and creative thinking issues in engineering education.

2.1.4 Curriculum Reforms in Engineering Education

Although it is accepted that creativity is very central to engineering, the development of creativity skills has not been given considerable importance in engineering curricula (Panthalookaran, 2011a). Therefore, reforming the engineering curricula would allow students to experience real world problem-solving processes, which enhance creativity (de Vere, 2009).

The American Society for Engineering Education (2010) aims to prepare engineering students for the work place by equipping them both with technical knowledge and social understanding of their environment. From an educational point of view, revisions in engineering curricula will enhance better design skills (Dym et al., 2005), and creative and innovative skills (Cropley & Cropley, 1998; Pappas, 2002; Santamarina, 2003). Amadei and Sandekian (2010) presents the rise of humanitarian engineering programs in engineering education in USA. This could be linked to ABET's (2017) expectations of including "human element in production" in engineering curriculum. 21st century engineers will be expected to make critical contributions to develop the quality of human life (Amadei & Sandekian, 2010).

Development in engineering curricula is a major issue for all nation's engineering organisations. Engineers Australia (2014) declares that: "Design is a primary function of the engineering profession and it should be seen as the inevitable central activity linking research to development and imaginative engineers must be attracted to" (Engineering Design: A National Asset). The National Committee on Engineering Design (NCED) submitted a proposal to Engineering Australia about restructuring university engineering courses within Australia. The aim is "to provide recognition that engineering is a creative profession as well as an analytical profession" (NCED, 2006).

Similarly, the US based Accreditation Board for Engineering and Technology (ABET), emphasizes the "design component" in engineering courses. ABET argues that design is not possible to teach in one course; design experience must accompany the students through their education (Sheppard & Jenison, 1996a). The Engineering Council, which is the national registration authority for professional engineers in UK, prepared Standards and Routes to Registrations (SARTOR), which defined the standards of education expected of an engineer. One of the guidelines in this document indicated that universities must teach their students "the ability of creativity and innovation" so that students can obtain full accreditation for engineering status. It is the university's duty to discover ways how to foster creativity (Baillie & Walker, 1998).

Besides engineering organisations, there are also educational organisations that have had an impact on curriculum reforms. A report on educating engineers for the 21st century published by The Royal Academy of Engineering (2006) in England highlights the importance of communication and team-working skills, suggesting that the content of the units in the education institutions must be aligned with the changing needs of the industry.

The CDIO Initiative (Conceive, Design, Implement, Operate) is a worldwide collaborative dealing with developing a new vision of engineering education by emphasizing "creative thinking". It offers an education model for undergraduate engineering education that is being adopted by a growing number of engineering educational institutions around the world (Crawley, Malmqvist, Lucas, & Brodeur, 2011). "The main motivation behind the initiative was the widening gap between engineering education and real-world demands" (Khalaf et al., 2013, p. 4). One of the standards of CDIO is "enhancement of faculty teaching skills" (CDIO, 2010).

Design has been given new prominence in the USA by an initiative of the National Science Foundation (NSF), which is an independent federal agency with the purpose of "supporting research and education in all fields of science and engineering" (NSF, 2009). The NSF has stated that engineering education needs a new system of faculty rewards and assessment methods which "promotes student learning" and "encourages adaptation" (Meyers & Ernst, 1995). NSF (2009) published a proposal about "Transforming Undergraduate Education in Science, Technology, Engineering and Mathematics" with a program called "Course, Curriculum, and Laboratory Improvement". This program supports the creation and adaptation of "learning materials and teaching strategies" about the way students learn. It encourages developing the faculty expertise by projects that enhance the understanding of how students learn STEM (Science, Technology, Engineering & Mathematics) topics (NSF, 2009).

Another important issue is the proposed change in the universities. It has been reported (Meyers & Ernst, 1995) that only a change in engineering college is not enough, but a comprehensive reform is needed regarding the whole campus and the undergraduate education.

2.1.4.1 Current Engineering Education Curricula

Current "traditional science model of engineering" curricula emphasise the basic science and mathematics for the initial years of the education (Khalaf, Balawi, Hitt, & Radaideh, 2013). Most importantly, it "focuses almost exclusively on lecturing" (Felder & Brent, 2005, p. 60). Engineering education focuses on solving well-defined, analytical problems without regarding the complementary skills that would help develop innovative solutions (Cropley, 2015b). There has always been a single approach in engineering education: "The professor lectures and the students attempt to absorb the lecture content and reproduce it in examination" (Felder & Brent, 2005, p. 57). de Vere et al. (2010a) think most engineering curricula focus solely on a theory-based engineering science approach and neglect creativity. However, engineering graduates must be "innovative, adaptable and creative designers" to be prepared for the requirements of the 21st century and this can only be achieved by deeper design experience, problem framing and creative process (de Vere et al., 2010a).

Daly et al. (2014) made a study on teaching creativity in seven engineering courses by using a case study methodology. Their findings support the idea that many courses include convergent thinking skills like analysing, reorganising and evaluating but also reveal there are gaps in teaching creative skills in engineering courses (Daly et al., 2014). Robinson (1999) states that the solution is educating students in a different way. The priorities must be changed in the curricula, teachers should be trained for promoting creative abilities and the partnership between educational institutions and industry should be promoted (Robinson, 1999). Researchers (Siu, 2012; Felder & Brent, 2005) highlight the importance of a more balanced approach to accommodate student needs.

Typical Mechanical Engineering curricula involves foundation, technical and management subjects. The reason for teaching engineering science is to support the students' ability to design (Dym, 2003). But engineering design teaching is limited only to Machine Design, Mechanical Systems Design and CAD based subjects. Given design problems are usually constrained and limited in scope (de Vere, 2013). Youssef and Kabo (2015) describe a Machine Design subject in general by highlighting the lack of engineering design process. The current structure does not support creativity during the idea generation and does not help students in decision-making. These engineering design subjects are limited in terms of actually delivering an effective design process, which negatively affects creativity/creative process.

2.1.5 Issues of Fostering Creativity in Engineering Education

There are several reasons for having concerns about engineering education, however the focus of the research in this thesis is on issues from design and creativity perspectives. Most engineering curricula currently work only on a theory-based engineering science approach and neglect creativity and the development of design and problem-solving abilities. Today's engineering education is based on narrow and out-dated learning theories (Törnkvıst, 1998). The general tendency in undergraduate engineering programs is to focus on the traditional lecture format (Rugarcia et al., 2000) and single correct answer (Felder, 1987), which leads to producing engineering graduates who have a "one problem one solution philosophy" (Mathews & Bailey, 1965). Felder (2006) adds that the traditional teaching model used in engineering education is not sufficient enough to provide motivation to students.

With technological breakthroughs, political and social impacts, engineering curricula has been loaded with several subjects for years but there are still some topics missing, such as design and creative thinking. If engineers are to design then they should be educated for this skill (Churches & Magin, 2001). But, “we cannot just add these new fundamentals to a curriculum that is already too full” (Wulf, 2000, p. 594). So the instructors are responsible for finding a balance among various engineering science and creative subjects (Kazerounian & Foley, 2007) because new engineering pedagogy needs to integrate design and project based learning into the curricula (de Vere et al., 2010a). Therefore, deeper philosophical implications of creativity are required for preparing graduates for the future (Törnkvıst, 1998). The next generation of engineers must learn by looking at things from several different perspectives and be capable of creating multiple hypotheses (Stouffer et al., 2004).

Pappas (2002) highlights the importance of innovation in engineering design teaching. Even though design is mandated as a key ingredient for a successful engineering program some educators still think that undergraduate engineering should focus on theories and principles (Ghosh, 2000). However, there is increasing pressure on engineers from industrial, professional and governmental institutions, all suggesting engineers should develop creative skills (Baillie & Walker, 1998). The United States National Academy of Engineering report (2004) states that an “emphasis on the creative process” will enhance development for future studies in “The Engineer of 2020” report.

Baillie (1998) identified the most challenging issue in engineering education as “facilitating students’ learning” by problem-solving skills, different learning forms, motivation, teaching approaches, time management and integrating new subjects. Green (2006), in his discussion paper, argues that the current problem in engineering courses in Australia is the decrease in design units, design application and design philosophy. Cropley and Cropley (2000) review the Government of Australia’s survey in 1999 about new graduates and conclude that Australia’s new engineering graduates are not suitable for employment due to their “skill deficiencies” in creativity and problem-solving. Churches et al. (2007) are also concerned about the quality of graduate engineers. They (2007) find the current mechanical engineering courses in Australia unsatisfactory in terms of problem-solving skills and add that it is not a simple task to quickly fix. Not only Australia but Europe (Nordstrom & Korpelainen, 2011) and the USA (Sheppard & Jenison, 1996a) are facing similar challenges in engineering education, which are causing many students to switch out of engineering.

Pappas (2004) declares that integrating "thinking skills and problem-solving into a science, technology or engineering curriculum" is the responsibility of higher education. The required skills must be integrated into the tight curricula and the people who are going to teach these skills must be determined to do that (Pappas, 2004). Incorporating more design principles into the engineering curricula in higher education will be inadequate unless there are suitable and capable staff who can deliver it (Richards & Carlson-Skalak, 1997). A related topic is the constraints of the curricula and the time pressure on students (Panthalookaran, 2011b).

Instructional materials about creativity, not enough time for an ambitious curriculum, lack of instructor knowledge on supporting students inhibit development in their creative skills (Daly et al., 2014; Felder, 1987; Kazerounian & Foley, 2007; Pappas, 2002; Richards, 1998; Tolbert & Daly, 2013). However, "the complexity of engineering practice" (Zhou, 2012a) has been assumed as the root of challenges.

2.1.5.1 First and Final Years of Engineering Education

Being aware of the deficiency of creative skills in engineering education, engineering faculties have started to focus on reforming the engineering curriculum. According to some researchers (Dym et al., 2005; Burton & White, 1999; Richards & Carlson-Skalak, 1997; Forbes, 2008; Baillie, 1998) it is important to focus on creativity early in the education process, starting from the first year so that it can be effectively introduced. Felder (1987) suggests using creativity-stimulating methods developed by psychologists or educational theorists. To get better benefit from these methods they need to be introduced throughout the curriculum (Felder, 1987).

Burton and White (1999, p. 327) identify reasons why design is an important subject for first year engineering classes: "To motivate and excite first year students, to introduce design concepts and projects early in a student's education, to promote teamwork and to introduce engineering tools". The first year design subjects support academic success of engineering students (Besterfield-Sacre, Atman & Shuman, 1997). They are believed to enhance student interest and retention in the engineering field, motivate learning and increase the performance in latter design subjects (Dym et al., 2005). Burton and White (1999) supports exciting and motivating first year students.

Due to the fact that engineering education is already highly loaded, educators (Adams & Turner, 2008; Forbes, 2008; West, Tateishi, Wright, & Fonoimoana, 2012) focused more on motivational subjects. Apart from first year reforms, there are also studies about improving the final years of engineering education to prepare students for the industry by teaching engineering design and by involving students in open-ended design projects (Dutson et. al, 1997). However, Churches and Magin (2001) depending on their analysis of the design teaching at Australian universities, argue that integrating design projects in the curriculum is not enough; students first need to learn how to design.

Liebman (1989) compares the Capstone Design Courses, at Georgia University in the United States, to throwing students into the lake without initially giving them a swimming lesson. Because these students have not taken any design units before it may be frustrating for them (Mahboub, Portillo, Liu, & Chandraratna, 2004). As Genco, Holtta-Otto, & Seepersad (2012, p. 76) state depending on their experimental investigation, engineering curricula need to undergo a reform "to strengthen students' innovation abilities throughout their undergraduate education". In short, engineering education must be updated according to current requirements.

2.1.6 Requirements to be Done in Engineering Education

It is widely accepted that developing creativity in engineering education is beneficial and crucial. Stouffer et al. (2004) state that integrating creativity into curriculum promotes communication, team working skills, synthesising ability and leads to better student-professor interactions.

Mills and Treagust (2003) reviewed engineering education in several countries such as the USA, UK and Australia and she argues that a traditional engineering curriculum cannot provide the current requirements of the industry. Henderson et al., (2011) give effective strategies to facilitate change in undergraduate STEM (Science, Technology, Engineering & Mathematics) education by doing literature reviews: Change strategies must be long-term interventions such as a year, and must involve changing the beliefs of the individuals. “Developing a successful change strategy means first understanding the system and then designing a strategy that is compatible with this system” (Henderson et al., 2011, p. 978).

Professional associations (ABET, Engineers Australia), educational institutions (National Committee on Engineering Design, National Science Foundation) and researchers (Bordogna, Fromm & Ernst, 1993; Cropley & Cropley, 1998; de Vere, 2009; Pappas, 2002; Santamarina, 2003; Zhou, 2012b) all suggest the reconstruction of undergraduate engineering education to make creativity a core part of the curriculum. Researchers (Churches & Magin, 2001; Kazerounian & Foley, 2007; Cropley & Cropley, 2000; Churches et al., 2007; Zhou, 2012a; Stouffer et al., 2004) state that creativity should be embedded in engineering curricula and it should be encouraged among engineering students because it is central to engineering and problem-solving (Petroski, 2002; Kazerounian & Foley, 2007; Charyton & Merrill, 2009; Panthalookaran, 2011a; de Vere, 2013).

A large body of the literature agreed that practical experience of design should become an integral part of engineering education and that more staff need to be engaged in the practice of engineering (Churches et al., 2007; Warsame, Boney, & Morgan, 1995; Wulf, 2000). Engineering education should support students in developing their problem-solving skills (Adams, Turns, & Atman, 2003). Bordogna et al. (1993, p. 6) suggests that the undergraduate engineering students must be educated to: “think across a variety of disciplines functionally as well as in terms of disciplinary depth”. Creative skill development is often missing in engineering courses. So, Daly et al. (2014) came up with some suggestions, such as doing further instructions on divergent thinking, encouraging students to accept ambiguity, being open to exploration or developing assessments for creativity awareness. “Hands-on engineering design” subjects are ideal for enhancing the teaching of creativity (Lasky & Yoon, 2011).

Baillie (1998) highlights training faculty staff for the new teaching approach. Churches and Magin (2001) focus on the lack of design specialists in engineering faculties and suggest a "designer-in residence" scheme to provide adequate mentoring for Australia’s future top engineering designers. Dinsdale (1991) supports the idea of a design specialist presence in engineering education.

One of the issues of engineering education is combining students' creative skills with engineering theory, which is the most significant aspect of being an engineer. For that reason, ingenuity and how to be ingenious should be a component of engineering education, along with creativity enhancing methodology (Abdekhodaee & Steele, 2012). Meyers and Ernst (1995) support the idea of engaging students in the education context for more effective pedagogies. Christy and Lima (2007) focus on the necessity of multidisciplinary approaches in engineering education to enhance creativity.

Rugarcia et al. (2000, p. 12) list the changes needed in engineering education to get a better performance outcome: "Revisions in engineering curriculum and course structures, implementation of alternative teaching methods and assessment of their effectiveness, establishment of instructional development programs for faculty members and graduate students and adoption of measures to raise the status of teaching". When changing from a traditional teaching model to active cooperative problem based learning, the best approach is to make the change gradually (Felder, 2006). Sternberg (2007) suggests that students must be given the opportunity to engage in creativity, receive positive encouragement and then be rewarded when they have demonstrated creativity. More emphasis must be given to assessment too, as it is very important in motivating students to learn (Daly et al., 2014).

To stimulate and foster creativity among undergraduate engineering students instructors need to prepare carefully selected, challenging questions in exams and open ended design problems (Ghosh, 1993). "To make the creative thinking as a personal habit or intrinsic capability, long term training and practice-oriented exercises are necessary" (Wang, 2007, p. 448). When considering all deficiencies, one aspect needs to be considered as well: Time. As the engineering curricula are already overloaded the addition of any new material needs to take 'time' into consideration (Lumsdaine & Lumsdaine, 1995).

However, some believe that change happens very slowly in academia, especially in the engineering sciences, (Pons, 2016) because engineering is a particularly conservative discipline (Daly et al., 2014).

2.1.7 Conclusion

The literature reviewed in this section informed these questions:

- What is in engineering curricula at the moment in terms of creativity?
- What are the issues in engineering curricula and what needs to be done?

The general situation of the current engineering curricula is analysed. The section began with describing the nature and difference of the engineering discipline from other education disciplines. Shifts in the history of engineering education were analysed to better understand the current situation. The issues and challenges around creativity teaching in engineering education were given. Curriculum reforms that have been carried out in different places were reported. Finally, the requirements needed to be done for enhancing creativity in engineering education was highlighted.

2.2 DESIGN AS A UNIT IN ENGINEERING EDUCATION

Creativity comes inherently with design thinking in an engineering education context (Thompson & Lordan, 1999; Dym et al., 2005; Pahl, Beitz, Feldhusen, & Grote, 2007). Creativity is an essential element in design thinking (Cross, 2006; Owen, 2007). Therefore, it will be worth understanding the role of design and design thinking in engineering education with regard to implementing creativity. As specified: "Engineering is design" (Engineers Australia, 2014), and "the purpose of engineering education is to graduate engineers who can design" (Dym et al., 2005, p. 103). Design plays a central role in engineering in addition to science (McGowan, 1998; Masi, 1989). Design is a major activity of every engineering curriculum (Li, Wang, Li, & Zhao, 2006; Dinsdale, 1991).

Several studies thus far have linked creativity with design pedagogy (Pappas, 2002; Cropley & Cropley, 2000; de Vere, 2009). Researchers (Pappas, 2002; McGowan, 1998; Dym, 2003) emphasise the role of design in learning engineering skills, practices and creative thinking. Hubka and Eder (2003) suggest supporting learning with theory and practice in design education. Engineering discipline should see design pedagogy as a model and potential for fostering creativity (de Vere, 2009). The creativity development in engineering education depends on the design focus of engineering courses (Daly et al., 2014). Without creativity engineers can be technically competent but not capable of innovation, so design should be a motivating factor in engineering learning in universities (de Vere, 2009).

McGowan (1998) suggests giving more emphasis on design in engineering courses. To develop cognitive skills and real world problem-solving abilities “design needs to have a central role in engineering education” (de Vere, 2009, p. 3). Even though there is design at the core of many engineering courses it is often taught from “an analytical perspective” (Anderson, 2013, p. 4) because by nature all engineering courses tend to be analytical (McGowan, 1998).

This section questions the need, the types and challenges of design thinking in engineering education. It reviews the description of design, design cognition and engineering design. This section also informs of design and creativity features in different engineering disciplines, with the aim of providing a ground for future benefits for ‘mechanical engineering’ education. The section concludes by acknowledging the roles of design thinking in engineering education and issues of teaching it.

2.2.1 Design and Design Thinking

The literature put forward the challenges of embedding design across a curriculum in practice (Terry & Harb, 1993). The meaning of design and design thinking must first be clarified. Design writer and educator Heskett (2002) mentions the complexity of defining design by stating “design is to design a design to produce a design”. It has so many levels to cause confusion and its meaning depends on who uses it, for what purpose and in what context (Heskett, 2002; Lawson, 2006). Design plays a crucial role in various fields like graphics, production, fashion, communication, architecture or engineering. In each of them, it has a different context. However, within the framework of this research the word design refers to the engineering design context.

Engineers Australia (2014) defines design as “a primary function of the engineering profession”. The definition of design by the Engineers’ Council for Professional Development in the United States is “the creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes” (Daly, Adams &, Bodner, 2012c). Design has been accepted as a key aspect in the engineering field.

Pahl et al. (2007) describe design as "an interesting engineering activity" affecting all aspects of human life. It is "a creative, open-ended activity" (Terry & Harb, 1993, p. 1594). It is not a linear process but rather looping and jumping between design problems, knowledge and solutions and therefore it is "an iterative process" (Zimmerman, 2003; Nguyen & Zeng, 2012). Design uses information, logic and creativity "to put forward possible concepts and to change existing perceptions" (p. 64), "it searches to do better ways of doing things" (de Bono, 1993, p. 68).

Design thinking "uses the concepts of creative thinking", it looks at a problem from different points and it "seeks to integrate these differing opinions into a wider, holistic solution to a given problem" (Fry, 2006, p.5). Razzouk and Shute (2012) define design thinking as both an "analytic" and "creative" process and also as an "iterative" and "interactive" process. It "is a problem-solving approach" (Zemke & Zemke, 2013, p. 450) and it helps "decision making" (Owen, 2007, p. 17). For the purpose of this study the word "design" will be used as a verb, thus drawing attention to the fact that design is perceived as a process.

2.2.2 Design Problems

An engineering design problem first needs to set a goal, then there must be some constraints indicating what can be or cannot be done and some criteria need to be fulfilled for achieving a successful solution (Cross, 2008; Wang, 2007). A design project is an effective way to enhance the learning in undergraduate engineering by increasing student interest in the subject and bridging the barrier between theory and practice (Mokhtar & Duesing, 2008).

Designers mainly deal with ill-defined or ill-structured problems (Demirkan & Hasirci, 2009; Törnkvıst, 1998). They come up with solutions to design problems by determining the problem and solution together. The goal is not to see the solution clearly at first sight (Cross, 2008). The designer needs to deeply explore the complex structured problems. There are no right or wrong solutions; assessments are done whether the solution is good or bad. There might be many variations of solutions to any given problem and these are related to how the problem is formulated (Cross, 2008).

Well-defined problems have a clear and defined goal and lead to a unique correct answer with no alternatives, by using known ways (Törnkvıst, 1998). Whereas ill-defined problems do not have definite formulation and solutions to problems (Cross, 2008). Open-ended problems encourage divergent thinking (Wulf, 2000) and they might have more than one acceptable solution (Runco, 2007). Ghosh (1993) supports giving engineering students open-ended problems because most of the 21th century design problems require creative skills to find solutions. Therefore, engineers need special training to successfully solve these problems (de Vere, 2013).

Designers need to define, redefine and do modifications to the problem to deal with ill-defined problems (Cross, 2006). Just introducing open-ended projects in engineering does not necessarily guarantee a creative output. Problems must be designed in a way to encourage using divergent thinking, and formulating the problem for analysis (Thompson & Lordan, 1999). Another counter-argument comes from Seidel (2004): Trying to stimulate engineering student's creativity with design exercises might not necessarily end up with positive effects. Engineering students often prefer exactness and predictable solutions and giving them an open-ended problem might discourage them and might actually inhibit their creative abilities (Seidel, 2004).

2.2.3 Design Cognition

Human beings have a long history of design thinking dating back to ancient civilisations. Cross (2006) claims that all people are capable to design and it is something that distinguishes us from other animals and machines. Understanding how designers approach design helps engineering students to be successful in their studies (Daly et al., 2012c).

As designing is an everyday activity, done by everyone, it is worth understanding the aspects and steps of this thinking process. Visser (2009) sees design as "a problem-solving activity", however it is not simply just that. When designers are asked about their nature of profession, they talk about the significance of "creativity" and "intuition", the ambiguous solutions to problems and the necessity of using sketches, drawings and models for exploring the problem and solution together (Cross, 2008). Designers fully understand the problem when they are actually solving the problem

(Cross, 2004). Pahl et al. (2007) describe the activities of designers as conceptualizing, embodying, detailing and computing.

Cross (2001a) explains design cognition by considering the results of protocol and empirical studies: Designers initially need to define the problem in a proper way, due to poorly defined design problems. They first need to understand and reformulate the problem to find a way to solve it (Cross, 2008). Then they generate solution alternatives where creativity takes place. Another important phase is the design process in which students and designers shift their behaviour and their approaches (Cross, 2001a).

The initial step in the design process is to frame the problems. Framing is identifying the solution space of a problem for doing exploration (Cross, 2001a). Frames can encourage designers to explore new designs. However, they can negatively affect the design process if they are fixations (Cross, 2001a; Cross, 2006). Cross's description of framing focuses more on the period before the design process. Cropley and Cropley (2010a) agree that understanding of framing happens when engineers confront a problem. There is a period of exploration in the creative design process, when problem and solution fields evolve together until a bridge emerges between them. This bridge links the problem to a solution, establishing a "problem-solution pair" (Isaksen & Treffinger, 2004). Because designers behave like ill structured problem solvers, they do not spend too much time in defining the problem. However, successful design depends on scoping the problem, changing the approach to collect problem information and prioritising criteria (Cross, 2001a).

2.2.4 Engineering Design

After the industrial revolution designing had become a separate recognisable entity, distinct from a craftsman activity. Engineering design has also been a human activity for many centuries (Eder, 1991). It is "a systematic, intelligent process in which engineers generate, evaluate, and specify solutions for devices, systems, or processes whose forms and functions achieve clients' objectives and users' needs while satisfying a specified set of constraints" (Dym et al., 2005, p. 104). It "deals with how things ought to be" (Vincenti, 1990, p. 237). ABET (2015) defines engineering design as "the process of devising a system, component, or process to meet desired needs. It is a decision making process (often iterative) in which the basic sciences, mathematics, and engineering sciences are applied". The American Society of Mechanical Engineers (2014) defines it as "the process of conceptualization, analysis, evaluation and verification of the form and function of products and systems".

Engineers Australia (2014) defines engineering as "the application of science to problem-solving" and design as "the creative expression of knowledge" and states that both are important. Engineering design is the conversion of an idea to an artefact, which engages both the designer and the maker. Hayes (2005) declares that the elements illustrating engineering design are both creative and artistic. Some authors emphasize the significance of teaching engineering as a creative design practice as well as a knowledge based and analytical science (Ferguson, 1993; Tornkvist, 1998).

The prior role of engineering designer was to apply his/her knowledge and experience to produce suitable solutions to given technical problems, then to optimize the chosen solution according to the technical, material, manufacturing or cost constraints (Court, 1998). Dekker (1995, p. 1) suggests that "engineering design is solving a problem, problem-solving is not engineering design". Everyone does problem-solving but there are some aspects that distinguish engineering design from problem-solving: The generation of concepts, initial layouts and configurations, choosing the one that has more potential, considering other alternatives and options (Dekker, 1995). In the engineering design process, "engineers need to apply their creative thinking ability to a specific problem and come up with multiple ways or possibilities in solving the design problem" (Ibrahim, 2012, p. 59).

2.2.5 Engineering Design Process

In engineering education discussions, engineering design became a major topic in attempting to understand the engineering design process of students (Atman & Turns, 2001).

After analysing different models of engineering design processes, T. Howard, Culley, and Dekoninck (2008) summarised it with six phases:

1. "Establishing a need" is the phase of identifying the design need.

2. “Analysis of task” phase refers to collecting data, clarifying the task, reviewing the prior art, researching the market and planning strategically.
3. “Conceptual design” is the phase of idea generation and development.
4. “Embodiment design phase” involves development, testing, experimentation and the validation process.
5. “Detailed design” is the phase of solving details and developing the work.
6. “Implementation phase” is the commercialisation, manufacturing and full production stage.

Dym, Little, & Orwin (2014) describe the design process by the following steps:

- Establishing a client’s objectives by asking them questions
- Identifying the constraints, which have the power to administer the design
- Establishing functions and suggesting ways to perform these functions
- Establishing specifications for the design
- Generating design alternatives
- Modelling and analysing
- Testing and evaluating
- Refining and optimising
- Documenting everything and communication

Pahl et al. (2007) describe the design process as follows:

1. “Clarify and define the task”
2. “Determine functions and their structures”
3. “Search for solution principles and their combinations”
4. “Divide into realisable modules”
5. “Develop layouts of key modules”
6. “Complete overall layout”
7. “Prepare production and operating instructions”

Atman, Chimka, Bursic, and Nachtmann (1999) conducted a study by analysing the verbal protocols of engineering students and argue that the design process in engineering should be adaptable with iterations and repetitions, even though previous studies showed that it follows a rigid framework. Vincenti (1990) supports the notion that the design process moves iteratively. Zimmerman's (2003) proposed design process is an iterative process of prototyping, testing, analysing and refining.

Forbes (2008) suggests that "idea generation" and "idea analysis" steps should be covered separately, because analysis, with its contradictory and critical thought process, can corrupt an idea generation phase. Although researchers and educators suggest generating a wide range of alternatives, sometimes a limited number of alternatives give the most appropriate strategy (Cross, 2001a; Cropley, 2006). On the other hand, some researchers (de Bono, 1990; Thompson & Lordan, 1999) think that developing many alternative solution concepts gives a better result.

Cross (2008) defines the descriptive and prescriptive model of design processes. In the descriptive model, there is a "solution focused nature of design thinking". The process is empirical by making designers use their previous experience and knowledge, and success is not guaranteed. The activities are in sequence, "exploration, generation, evaluation and communication" (Cross, 2008, p. 30). Initially in this four-stage design process model, the ill-defined problem needs to be explored, then the concept or idea is generated and afterwards evaluation must take place. After evaluation, the process might lead you directly to the last communication phase or with an iterative loop you turn back to the generation phase and continue again from there (Cross, 2008). Cross's (2008) engineering design process and the methods used in this process are summarised in Appendix I.

In descriptive design models, "they describe the elements of the design process". In prescriptive design models, "they prescribe what must be done during the design process" (Dym et al., 2014, p. 19-20). Prescriptive models emerged after descriptive ones and they provide a design methodology in which more analytical work takes place (Cross, 2008). However, "creativity needs to be present at all stages of the design process" (Court, 1998, p. 151).

2.2.5.1 Sketching in Engineering Design Process

Although mathematics has been used as the language of engineering for the last fifty years designers use different languages, like drawing and sketching, because "visual thinking is an intrinsic and inseparable part of engineering" (Ferguson, 1993, p. 47).

“Drawing and sketching have been used in design for a long time; long before the Renaissance” (Cross, 2006, p. 35).

“Sketching is one of the most important activities in the design and development of new products” (Rodgers et al., 2000, p. 451). “Sketches allow the designer and engineer the opportunity to explore as many concepts as possible in an efficient and effective manner, before moving into the detailed design stage” (de Vere, 2013, p. 42). Although research links sketching with creativity, engineering curricula is not sufficient to develop the sketching skills of the students which is necessary for design conceptualisation and communication. This limits the engineering graduates to explore design possibilities (de Vere, 2013).

Ullman, Wood, and Craig (1990) define drawings as “mechanical design graphic representations” and sketches as “freehand drawings”. de Vere, Melles, and Kapoor (2012) describe sketching as “the first language of designers”. They are significant skills both for designers and engineers by enabling the experience of an iterative creative design process (de Vere, 2013). “Sketching helps the designer to find unintended consequences” (Cross, 2001a, p. 90). According to Öhrling, Holmqvist, and Hakansson (2012) studies show that there is “strong correlations between the quantity of sketches and the quality of the result” (Öhrling et al., 2012, p. 1). Valentine (2012) states that drawing is an important skill “to communicate design” for engineers. Sketching enables the person to develop solutions to an ill-defined problem by using mental imagery (de Vere, 2013). Despite the fact there is evidence that drawing has positive effects in design creativity, engineering curricula do not focus on freehand drawing skills, which accordingly limits engineering graduates’ creative potential and communication (Cropley & Cropley, 2000; Zemke & Zemke, 2013).

The importance and necessity of sketching and drawings have been highlighted by many researchers as important not only for the engineering design process but also for the development of creativity (de Vere, 2013; Cross, 2008; Valentine, 2012; Ferguson, 1993). They should be part of engineering curricula (Zemke & Zemke, 2013). There have been studies showing the difficulties in doing this (Kuys & de Vere, 2010) as ME students are not taught the necessary design skills required to develop appropriate sketches. Unfortunately, many engineering faculties rely just on CAD and neglect freehand drawing and sketching ability in their curricula (de Vere, 2013). de Vere et al. (2010a) did a comparative evaluation of aptitude in problem solving in engineering education and argue that the difficulties of ME students in sketching limit their ideation and design progression.

Ullman et al. (1990) draw attention to the importance of drawing during the mechanical design process. Informal sketches help the engineer to communicate with the others and to better develop the idea on paper. If the importance of drawing during the design process was thoroughly understood the skills needed to be taught to engineers could easily be established (Ullman et al., 1990). Designers need to start with freehand sketches in order to visualise the desired design, to develop new ideas and to compare alternative ideas (Ferguson, 1993). Design engineers should be exposed to more sketching, along with project based learning early in the curriculum, to be more creative and adaptive (Kuys & de Vere, 2010). That would also enable them to better communicate with each other during the design process. Because sketching is a vital part of design process in engineering design.

2.2.6 Mechanical Engineering Design vs. Product Design Engineering

Mechanical Engineering is described as the exploration of the design of technology with physical motion (Swinburne University, 2015). Mechanical engineers have high levels of engineering science knowledge, technical understanding and analytical skills. However, they lack creativity and design skills, and an understanding of user needs and user-product interaction (de Vere, 2013). Therefore, “a new engineering discipline is required for new product development” (de Vere, 2013, p. 55).

Product Design Engineering (PDE) education first emerged in Scotland in the 1980s as a response to a changing industry and its demands (de Vere et al., 2010b). PDE was a new engineering curriculum, including elements like creative ability, an understanding of the social and environmental effects and a human centred and responsible approach. de Vere (2013) explains that the integration of industrial design and mechanical engineering courses developed creative and adaptive engineering designers. Kuys, Usma-Alvarez, and Ranscombe (2014) explain that PDE is a “convergence of two diverse disciplines”. The graduates of PDE are trained to be proficient both in design and engineering roles (de Vere, 2013), and to combine “creative thinking of design” with “analytical thinking of engineering” (Kuys, Velasquez, Thong, & Glover, 2012, p. 1).

Design schools have different sets of values in the application of design, depending on which tradition they are coming from. This difference is explicitly presented in the debate of more art-based Cranbrook and more science-based Illinois Institute of Technology (IIT) design schools (Klinker & Alexis, 2009). Cranbrook designers are expected not only solve functional problems, but also make products that create a new culture. They believe “great design is about meaning first” (p. 54). Whereas, in IIT good design is based on “facts, not intuition”. They also talk about culture, but rather based on “an existing culture, not create new ones” (p. 55). The authors (2009) claim that design is different than innovation; design aligns more with art and innovation aligns more with business (Klinker & Alexis, 2009). In this respect, Swinburne’s PDE can be considered having both traditions.

PDE’s holistic view distinguishes it from ME’s “conservative, traditional approach” (de Vere, 2013). PDE graduates and PDE Program Coordinators throughout the world put forward the difference of PDE from ME. PDE graduates are considered to be better communicators, better project managers and be more innovative (de Vere, 2013). They cover all aspects of a product development, whereas ME students are purely mechanistic. PDE graduates are more capable of coping with complex, open ended and multi-disciplinary problems, whereas ME graduates have a deeper technical knowledge. ME graduates solve a problem as a technical system, without considering human social factors, unlike PDE graduates (de Vere, 2013). de Vere et al. (2010a) compared these two engineering disciplines with a comparative evaluation by observing, evaluating the design outcomes and conducting student surveys. The results clearly showed that developing a creative design focus is beneficial within all engineering curricula.

Opening PDE courses in which design is integrated does not necessarily solve the creativity issues in other engineering fields. PDE might be considered to have an answer to including creativity in engineering education, but it is not the only answer. The rest of the engineering courses still need to include creativity in educating engineers who can bring innovative solutions to existing global problems.

2.2.7 Thinking Types in Design Process

Descartes emphasizes the importance of thinking by saying "Cogito ergo sum" (I think, therefore I am). The Nobel Prize Winner Sir William Henry Bragg (1915) says, "The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them". There is a large volume of published studies describing the role of thinking in education but the first step is to accept that thinking is a skill, not a gift (de Bono, 1996).

de Bono (1993, p. 73) emphasizes the importance of creativity in the thinking process. People usually think, "logic" has the major role in thinking and ignore "perception". Logic can only deal with what is there, whereas perception is interested in what is not there (de Bono, 1996). In today's schools the importance is given to the truth, not the possibilities. Thus, a traditional thinking system is excellent as it involves analysis, judgment, argument and criticism. But it is not sufficient because it does not deal with perception, which is the most important part of everyday thinking (de Bono, 1996).

Treffinger, Isaksen, and Dorval (2000) propose thinking skills can be taught to enhance one's creativity. The creative process involves and evolves with the exploration of connections between different areas. People should look at information from different perspectives for making connections between them and so have a deeper understanding of the key points. To generate new ideas from old ones we need to look to making new combinations or to delete and replace some elements. Creativity is not just about developing new ideas, but also useful ideas which make an impact (Treffinger et al., 2000).

2.2.7.1 Creative Thinking and Critical Thinking

Critical thinking has been traditionally based on Aristotelian logic and deductive reasoning studies (Bleedorn, 1993; Li et al., 2006). It involves "examining possibilities carefully, fairly, and constructively, and then focusing thoughts and actions by organizing, analysing, refining and developing possibilities, ranking or prioritizing options, and choosing or deciding on certain options" (Treffinger et al., 2000, p. 7). Creative thinking is "the best way of approaching the most difficult problems" (Armentano, 2012, p. 734). Sternberg (2003) explains creative thinking as redefining problems, analysing the ideas, selling these ideas, being knowledgeable, surmounting obstacles, taking risks, willing to grow, believing in oneself, tolerating ambiguity, allowing time and mistakes.

Treffinger et al. (2000, p. 3) express that “creative and critical thinking are two complementary, mutually important ways of thinking”, and they are both necessary for engineering field. Creative thinking is a divergent process, whereas critical thinking is convergent. In the first one, the activity is “generating” a wide variety of ideas and possibilities and in the second one, the aim is “focusing” on a single goal (Treffinger et al., 2000). The Australian Curriculum (2014) Report emphasizes that students need to develop both critical and creative thinking as part of their education “to generate and evaluate knowledge, clarify concepts and ideas, seek possibilities, consider alternatives and solve problems”. According to the report, The Melbourne Declaration on Educational Goals for Young Australians recognizes that “critical and creative thinking are fundamental to students becoming successful learners”.

Considering many definitions of creative thinking (Ibrahim, 2002; Cross, 2008; de Bono, 1995; Treffinger et al., 2000) this thesis accepts that it is a process of thinking, enabling the engineer to solve design problems by generating a variety of alternative possible solution ideas. In order to achieve creative thinking other types of thinking like “lateral thinking” or “divergent thinking” are helpful.

2.2.7.2 Lateral Thinking

Lateral thinking is closely related to creativity and it can be learned, practised and used. de Bono (1993) defines lateral thinking as “the other sort of thinking”, (p. 52) meaning the thinking that is “not linear, sequential and logical”. Normal logic is concerned with “truth” but lateral thinking is concerned with “possibilities” and “changing concepts and perceptions” (de Bono, 1993). Some believe it is another term for divergent thinking, but de Bono (1993, p. 55) thinks, “divergent thinking is interested in multiple possibilities, just like lateral thinking, but that is only one aspect of lateral thinking”. Runco (2007) sees lateral thinking as being like brainstorming, as both look for alternatives and criticism is postponed.

People generally expect things to happen in a certain way. However, creativity happens not on the main track but on the side-track. That is where the term “lateral” comes from.

Lateral refers to "moving sideways across the patterns instead of moving along them as in normal thinking" (de Bono, 1993, p. 15). It prefers to generate alternatives instead of developing one stream of thought. Unlike natural thinking, which is searching for the best possible approach, lateral thinking is concerned with producing many possible alternatives. Design is an appropriate venue for practising lateral thinking (de Bono, 1993).

According to de Bono (1993), anybody can use lateral thinking tools for generating new ideas. Some researchers (Waks, 1997; Mitchell, 1998) support implementing lateral thinking in education. However, Li et al. (2006) find it "unsystematic and inefficient" when applied to technology systems and product design, because it relates more to general creativity.

2.2.7.3 Divergent Thinking and Convergent Thinking

Divergent and convergent thinking are both considered as requirements for creativity too. About 50 years ago Guilford and Torrance both encouraged the enhancement of divergent thinking by expecting multiple responses to single problems. Although divergent thinking is linked with creativity (Welkener, 2013), some theorists put forward the idea that it plays an important but small role in creativity (Plucker, Beghetto, & Dow, 2004). It is necessary but not sufficient for creative problem-solving (Clapham, 1997).

Convergent thinking is more about details and the evaluation of the design, it involves selecting a feasible proposal from the alternatives. On the other hand, divergent thinking is related to concept design and the generation of alternatives (Cross, 2008). Liu and Schonwetter (2004) summarize the difference - Convergent thinking deals with singularity, whereas divergent thinking deals with variability. Convergence is focused on finding the only "correct answer or solution" (Cropley, 2006; Campbell, 1985). Whereas divergence is focused on discovering and solving problems by making unexpected associations or applying the known in unusual ways (Cropley, 2006), which allows going in different directions. Most importantly, both are required for creativity (Bleedorn, 1993; Cropley & Cropley, 2010b; Fry, 2006) and educators should provide instruction and practice in both types of thinking in engineering education (Felder, 1988; Court, 1998). Both are equally needed for effective novelty (Cropley, 2015a).

However, engineering education promotes and develops only convergent thinking (Cross, 2008).

2.2.8 Challenges of Design Teaching in Engineering Education

Teaching design has a different approach than traditional teaching so teaching it to engineering students brings more challenges. “Transmitting knowledge is the easiest part of teaching” (Woods, Felder, Rugarcia, & Stice, 2000, p. 12). Promoting creativity is the biggest challenge when teaching a design approach to engineering students (Kuys & de Vere, 2010). The iterative process is hard for engineering students when they are struggling with open-ended questions because they are mostly familiar with linear processes where there is a definite answer (Kuys & de Vere, 2010).

Another significant teaching problem in engineering education is to find an appropriate faculty member to teach creative problem-solving (Churches & Magin, 2001; Mathews & Bailey, 1965). Otherwise design classes will be no more than a series of lectures in applied mathematics drawn from a text-book. There are many books providing theoretical analysis but none of them provide the practical design experience with careful mentoring, which must be at the core of a design unit (Dinsdale, 1991).

Engineering design is generally taught by giving open-ended design problems, which do not fully support students’ cognitive learning needs in design (Zemke & Zemke, 2013). Many subjects in engineering curricula teach analysis that develops step-by-step style solutions to well defined problems. Whereas, design problems are ill defined and the step-by-step way of learning does not help. The biggest difficulty in engineering design subjects is not about learning the new topic, but learning the new approach (Zemke & Zemke, 2013).

2.2.9 The Role of Design Thinking in Engineering

National Academy of Engineering (2004) foresees that the engineers will exhibit “practical ingenuity” when describing the attributes of the engineers in 2020. It was already mentioned in Chapter 2 that the word engineer comes from the Latin word “ingenium”, which means engineers have always been ingeniators. However, in the future, as the world’s complex problems increase, there will be need for engineers’ practical solutions more than ever. Engineers will continue to use science and practical ingenuity in identifying and solving problems (National Academy of Engineering). Therefore, creativity and design thinking will also be crucial skills of the future engineers.

The Moulton Report, prepared for Engineering Design Education for the Design Council in UK has a similar goal: "Engineering should be taught in the context of design". Johri, Chen, and Lande (2009) believe an approach to design, including creative thinking in engineering education, gives a better result. Because the design experience brings opportunities for students to gain skills in design, teamwork, communication and understanding global engineering problems (Atman, Adam, & Turns, 2000).

Traditional engineering pedagogy is criticised for not raising engineering practitioners. However, design pedagogy, by its experiential learning process, fosters creativity and develops problem-solving ability (de Vere et al., 2010b). de Vere (2009) suggests that engineering should use design pedagogy as a model for fostering creativity. de Vere (2009, p. 2) declares that "without a focus on design activities and creativity, engineers will graduate technically competent, but not capable of innovation". He suggests that the university has to foster creativity during design process, because design is fundamental to engineering practice. Another critical point is to "advance our teaching in innovation and design processes" (White, Wood, & Jensen, 2012).

Cropley and Cropley (2010a) examine the idea that design brings more opportunities for creativity due to the "openness" of ill-defined problems. The introduction of creativity into the design process in engineering class exercises encourages students' achievement and capability (Atman et al., 1999). Norman (2014) believes that design thinking skills are necessary factors for future creative leaders in technology, business, and education. It can be concluded that design skills are at the centre of engineering practice in industry and must therefore be at the core of engineering education.

2.2.10 Conclusion

This section covered the literature by answering how design thinking helps to increase creativity in engineering education. The general condition of design teaching in engineering education, engineering design and its process are reviewed. Thinking types in the design process and the challenges of design teaching in engineering education are described. The literature suggests that design thinking and creativity are essential to engineering. The next section will question the need for creativity and innovation in engineering education.

2.3 CREATIVITY AND INNOVATION IN ENGINEERING

This study shows the requirement of creativity in undergraduate engineering education. Researchers asked relevant questions that will be addressed in this section:

- What is creativity in an engineering context, how it can be learned? (Johri et al., 2009)
- Why is creativity important in an engineering educational context? (de Vere, 2013)

Creativity is “the essence of engineering”, however, it is not explicitly taught or promoted in the engineering curriculum (Santamarina, 2003). Pappas (2002) states that integrating creative thinking into the engineering curriculum is still fresh to engineering design programs. In recent years, engineers are seen as followers and technologists rather than creative and successful leaders as they were in the old times. The main reason for that is the inadequacy of the engineers in the creative areas of their work. (Arciszewski, 2014). Therefore, engineering needs to be reconnected to creativity.

Creativity is one of the main goals of engineering education (de Vere, 2013; Liu & Schonwetter, 2004; Pappas, 2002; Santamarina, 2003; Zhou, 2012c). It is a critical skill that engineering students need to possess (Dinsdale, 1991; Csikszentmihalyi, 2006). It is crucial in the practice of engineering (Mitchell, 1998) and must be part of the learning process in engineering education (Abdekhodaee & Steele, 2012). Vincenti’s (1990, p. 3) believes that “what engineers do, depends on what they know”. This can be interpreted that if engineers possess creative thinking skills then they can come up with more creative solutions.

What is meant by creativity and what needs to be changed in the education of it must be specified In order to train creativity effectively (Cropley & Cropley, 1998). Correspondingly, this section aims to define and describe the nature of creativity and its positive effects in an engineering context. The study questions how creative thinking can be learned and why it is important for engineering students.

2.3.1 Description of Creativity

Due to the complexity of creativity the universalisation of it in our current world is not possible (Craft, 2003). There are many different descriptions, changing according to the disciplines (Treffinger et al., 2002), to the culture (Liu, 1998) or to context (Csikszentmihalyi, 1997). Creativity etymologically comes from the Latin word ‘creare’, which means, “bring forth” (Oxford Dictionary, 2014). The term creativity dates back to ancient Greece and Rome; however, modern educators and psychologists started to become interested in the concept of creativity in the mid-20th century (Treffinger et al., 2002).

As creativity is expressed differently in different domains, clarifying these differences is important (Runco, 2004). Psychology focuses on the “individual’s creativity” to identify cognitive capacities, whereas social psychology focuses on the “process of creativity” and sociology focuses on “the environmental process” (Törnkvıst, 1998). However, researchers describe creativity from an engineering perspective as “functional creativity” to indicate the importance of functional requirements in the engineering field (Cropley & Cropley, 2010a). Creativity “helps engineers with complexity, it helps shape new knowledge, find new solutions to problems, engage in technologically innovative activities and lead to new designs” (Zhou, 2012c, p. 99).

Hutchinson (1931) used the word “practicality”, Bruner (1962) used “effective surprise”, Cropley (1967) used “worthwhile”, Messick (1965) used “appropriate” Kellner (1965) used “relevant” and Stein (1953) used the word “novel” for describing creativity (as cited in Runco & Jaeger, 2012, p. 92). Williams et al. (2012) mentioned “novelty” and “appropriateness”. Runco (2007) mentions that “imagination” is frequently associated with creativity, which is human thought helping to reproduce images or concepts. Stouffer et al. (2004, p. 6) use “making the strange familiar” phrase to better describe creativity. Similarly, von Oech (1998, p. 11) defines the same concept by “making the ordinary extraordinary” by changing our perspectives or playing with our knowledge.

After reviewing the literature, Runco and Jaeger (2012) argue that a standard definition of creativity must include “originality” and “effectiveness”. Being effective can be defined as being useful, fit or appropriate (Runco, 2007; Runco & Jaeger, 2012). Cropley (2015a, p. 218) describes creativity as “effective novelty”. Many researchers revealed the two distinct faces of creativity: “Novelty” and “usefulness” (Amabile, 1983; Thompson & Lordan, 1999; Plucker et al., 2004). West et al. (2012) define them by different terms: “Originality” and “appropriateness” (p. 243). Abdekhodaee and Steele (2012) bring another criterion for creativity besides novelty and usefulness: “Understandability”, meaning not resulted by chance or accidentally, but can be repeated if wanted.

Some researchers (de Bono, 1993; Wang, 2007) think creativity is the ability of bringing new things into existing, or “the ability to generate new ideas or new association between existing ideas” (Kazerounian & Foley, 2007, p. 763). However, it “is not just about generating ideas; it is also about finding solutions to problems” (Thompson & Lordan, 1999, p. 28). Gold (2007) emphasizes that it is not only about making things, it is making things that never existed before. Oxford Dictionary (2015) defines creativity as a process as well as a quality for producing “a valuable artefact accomplishing certain tasks in an ingenuous and original way”. Nevertheless, Weisberg (2006) does not include the “value” criterion when defining creativity, because it changes over time. Something that has a value might not have it in another generation. Therefore, Sternberg (1999) states that creativity must be defined within a context, it does not exist in isolation.

There has been a shift in the focus of researchers from what creativity is and more to where it happens (Csikszentmihalyi, 1988). Runco’s (2007) and Sternberg’s (2006) handbooks on creativity describe the significant advances in the field. Guilford (1950) and Torrance (1987) were the pioneers believing that creativity can be understood by scientific ways. Then, other researchers (Amabile, 1983; Sternberg & Lubart, 1996; Sternberg, 2006; Runco, 2007) followed them, showing that creativity is a growing and valuable subject in the academic community.

Lau and Chan (2004) describe two types of creativity: Artistic and cognitive. Artistic creativity refers to the creation of an artwork by the expression of one's ideas and emotions while cognitive creativity refers to coming up with solutions to problems. Amabile (1983) explains creative behaviour as the result of configurations of personality characteristics, cognitive abilities and social environments. "Creative thinking and creative problem-solving are aspects of human cognition" (Feldhusen & Goh, 1995, p. 244). Thompson and Lordan (1999) describe two cognitive styles of creativity: "adaptors" prefer to take and improve the idea to do things better whereas "innovators" prefer to look at problems from another perspective and to do things differently. But, both are able to create ideas and solutions.

2.3.2 Creativity vs. Innovation

Creativity and innovation are often mixed concepts. Some believe that one follows another, while others believe they have the same meaning. In this research one intention is to distinguish creativity and innovation and to explain why there is a need for both in the engineering field. These terms are used interchangeably but they have different characteristics (West et al., 2012).

From an engineering perspective creativity, can be seen as the initial requirement in the innovation process. It "is the development of ideas, whereas innovation is the application of ideas" (Zhou, 2012a, p. 350). Like Zhou (2012a), Mumford, Hunter and Bryne (2009) also see creativity as the basis for innovation. Creativity is bringing something into being or producing an original outcome. Whereas innovation is changing, modifying or adding something new to an existing product or process (Badran, 2007; Herrmann, 1999). Similar to previous thoughts, Anderson (2013, p. 2) sees creativity as "the act of coming up with original solutions relevant to problem-solving" and innovation is "the implementation of a creative solution". Cropley (2006) sees creativity as "the development of novel products" and innovation as "the process of developing and commercialising creative ideas" (p. 561). Gurteen (1998) describes creativity as the idea generating process and innovation as putting the generated ideas into action. Innovation is the "value adding stage of the creativity process" (Hayes, 2005, p. 9). Runco (2007) sees innovations as the extensions and modifications of what existed previously. However, not all creative thinking results with innovation and conversely "innovation represents one application of creative thinking" (Runco, 2007, p. 381). Creativity is a "necessary but not sufficient condition for innovation" (Amabile, 1996, p. 1155). Previous research shows that there is a consensus among researchers that innovation comes after the creative process and adds something new to what already exists. Stouffer et al. (2004) think they are very similar and state that both lead to the same end when approaching technological matters.

This study accepts the argument of T. Howard et al. (2008, p. 160) indicating that "without creativity in design, there is no potential for innovation". Gurteen (1998) agrees that for turning an existing idea into action creativity is not enough; innovation is needed. Creativity and innovation are both important for the 21st century engineers (Panthalookaran, 2011a). This study accepts that creativity is the capacity and the ability to generate original ideas while innovation is the implementation and turning of these ideas into reality and both are necessary in an engineering context.

2.3.3 Can Creativity be Learned and Taught?

There are two notions of creativity in history (T. Howard et al., 2008). The romantic view states that creativity is a gift, it is innate and cannot be learned, whereas the rational model puts forward the idea that creativity is not special to some people and it can be learned and taught (Williams et al., 2010; Amabile, 1983; de Bono, 1995; Stouffer et al., 2004; Fry, 2006; Runco, 2004; Johri et al.; 2009; Lin, 2011).

There has been a debate whether creativity is a talent or can be achieved by practice. Court (1998) believes that creativity is "not a magical ability"; if you can think it is possible to learn thinking creatively. de Bono (1995) notes that creativity is not a natural process in the brain and he believes that is not limited to some special people. Because the normal behaviour of the brain is set up to routine patterns, there is a need to provoke it. The brain is not designed to be creative, therefore creativity needs practice (de Bono, 1993). On the other hand, Weisberg (2006) questions whether in some domains like music or painting talent is more important than practice and gives Mozart or Picasso as examples. de Bono (1993) believes that even if Mozart or Einstein are naturally gifted, as some argue, it should not mean that creativity cannot be learned. For some creativity comes naturally but when training is provided the level of creativity can be raised (de Bono, 1993). This highlights the importance of experience and practice in the field, whether or not creativity is a natural gift. Cropley (2015a) argues that creativity in engineering can also be learned and improved. Williams et al. (2010) declares that a holistic approach is needed for creativity in education and this can be realised by replacing the romantic idea of creativity with the rationalist model (Williams et al., 2010). However, Sternberg (2003) criticizes the fact that the schools do not give the necessary importance to creativity.

"Not only can creativity be taught, it is taught effectively at all levels of education, from kindergarten to graduate school" (Stouffer et al., 2004, p. 6). However, Abdekhodaee and Steele (2012) separate learning from teaching by arguing "creativity cannot be taught, but learned". Besides the literature arguing that creativity can be taught, Lau et al. (2009, p. 71) claim "creativity cannot be taught but creative thinking techniques and procedures can". From a similar perspective, T. Howard, Culley, and Dekoninck (2007) suggest we use the term "to foster" creativity instead of teaching creativity.

This study accepts the views that creative potential exists among all people and anyone can learn to be creative and has the potential to do so (Sawyer, 2006; Armentano, 2012; Treffinger et al., 2000).

2.3.4 The Ps of Creativity

From a psychological and educational perspective, the traditional framework for investigating creativity is the 4Ps approach (Rhodes, 1961), which has been used and suggested by many other researchers (Thompson & Lordan, 1999; Treffinger et al., 2002; Runco, 2004; Cropley & Cropley, 2010b; Williams et al. 2010; Feldhusen & Goh, 1995). These Ps are the Person, the Product, the Process and the Press. In the context of this study. The Person is the student engineering designer, the Product refers to the produced outcome by the students, the Process is the approach to design outcomes and the Press refers to the environmental factors in play during the process (Cropley, 2015a).

Person "includes the traits, attitudes, and behaviours of the creative individual" (Treffinger et al., 2002, p. 20). "Product is considered as the outcome of the design process", "process is the person's journey throughout the designing activity until creating a product" (Mann & Tekmen-Araci, 2014). Press is "the shell in which the process takes place" (Hasirci & Demirkan, 2007, p. 262). However, they don't operate in isolation from each other (Cropley, 2015a). Therefore, a holistic approach is a must in studying creativity in order to fully understand it.

2.3.5 Creative Process

There have been many models of the creative process. The traditional problem-solving method focuses on product or technical systems, but may not recognise the design process from a creative cognition perspective (Li et al., 2006). The creative process is addressing the idea generation and validation processes. Therefore, it is clear that the "creative process is a significant subset of the design process" (T. Howard et al., 2007, p. 9). Evans and Smith (2010) support that the creative process is always part of the design process.

T. Howard et al. (2008) summarise the phases of the creative process under four different headlines by analysing suggestions:

1. Analysis phase is the preparation phase, which includes fact-finding and problem defining.
2. Generation phase is the incubation, illumination and inspirational phase in which the ideas are generated.
3. Evaluation phase is solution finding and verification phase where solutions are developed and evaluated.
4. Communication / implementation phase is the presentation and the acceptance-finding stage.

Cross (2008) gives the sequence of a general creative process: "Recognition" is the initial realisation that a problem exists. "Preparation" is the action to fully understand the problem. "Incubation" is the period of leaving the mind to rest allowing the subconscious to do the work. "Illumination" is finding the key idea for the solution, often happening suddenly. "Verification" is the last phase of developing and testing the idea (Cross, 2008, p. 54). During the idea generation process many researchers mentioned "incubation", "illumination" (Campbell, 1985; Cross, 2008) and "inspiration" (Piirto, 2011) processes. Piirto (2011) explains the impact of inspiration as being like "an energy that cannot be forgotten" (p. 43). The inspiration dominates all ideas and it becomes hard for the person to focus on other things. It can start with vagueness but it has the authority. The creator is attracted by the inspiration (Piirto, 2011). Akin and Akin (1996) analysed the sudden insight during a creative process in an architectural design context, which they defined as the "A ha!" moment. When there is a creativity investigation, recognising the "sudden onset of a creative insight" is highly required (Akin & Akin, 1996, p. 4). Chandrasekera, Vo, & D'Souza (2013) defined the same concept as the "sudden moments of inspiration" as "the moment where the designer gets an insight into the design solution and/or the problem frame". These inspirational moments direct the design process into innovative solutions (Chandrasekera et al., 2013).

Csikszentmihalyi's (1997) creative process classification is very similar: Preparation, Incubation, Insight, Evaluation, and Elaboration. Along similar lines Liu and Schonwetter (2004) summarize the creative process by four phases: The "preparation" phase is defining and reformulating the problem, the "generation" phase refers to generating many solutions, the "incubation" phase is the subconscious problem-solving and the "verification" phase analyses and evaluates all the solutions.

According to Treffinger (1995) creative process is a loop following one another: "Understanding problem" is the first significant phase in a creative process. When the statement of problem has been formulated then it is time for generating solution alternatives. When the person has a number of promising options it is time for refining and developing them (Treffinger, 1995).

2.3.6 Factors Accelerating Creativity

It has been suggested that knowledge is a key element (Li et al., 2006; Ghosh, 1993; Sternberg & Lubart, 1996), which "can either help or hinder creativity" (Cropley, 2015a, p. 120). In order to come up with new alternative possibilities a person needs to have a store of ideas that might be altered or combined; therefore, intellectual curiosity and a large knowledge base are important to enhance creativity (Wang, 2007). Nonetheless, knowledge alone will not make people creative (von Oech, 1998; Li et al., 2006). de Bono (1993) argues that without creativity people cannot use their knowledge and experience with full potential. It enables people to integrate new knowledge with the old. Both arguments feed each other, that knowledge feeds creativity and creativity helps people to use their knowledge.

The importance of motivation for creativity is emphasized many times in the literature (Amabile, 1998; Sternberg & Lubart, 1996; Sternberg, 2006; Cropley & Cropley, 2010b; Lin, 2011; Piirto, 2011; Adams & Turner, 2008; Torrance, 1987). Motivation is a very important factor affecting the learning process (Berglund et al., 1998), coming in two different ways. The first one "arises from the individual's positive reaction to qualities of the task itself", it is intrinsic. The other one is extrinsic that "arises from sources outside of the task itself" (Amabile, 1996, p. 115). Motivation is the willing of doing, curiosity, trying again and again, looking for further alternatives and trying things out, which needs time and effort (de Bono, 1993). Expertise and creative thinking are an individual's sources but motivation is the determinative factor about what people will do. A designer or scientist can have great creative skills and knowledge but without motivation s/he will not do anything (Amabile, 1998).

Kazerounian and Foley (2007) propose factors called "Maxims of Creativity" to foster creativity in engineering education:

- Open mind: If students are taught to see things from different perspectives it might help them to understand that the obvious answer is not always the best one. Runco (2007) and Sternberg (2007) also argue that redefining the problem or situation is a strategy to develop a creative habit.

- Ambiguity: There is an unidentified time between the question and the answer in design process; students need to tolerate this ambiguous process. von Oech (1998) suggests taking advantage of ambiguous, random, and unexpected situations for stimulating creativity. Tolerance of ambiguity is essential to not focusing on only one solution (Piirto, 2011).

- Iterative process: For a creative process to be effective enough time must be allowed for a full iterative process because such a process occurs in a cycle of stages.

- Rewarding creativity: If educators encourage creativity the students will be more enthusiastic about attempting it.

- Showing examples: Educators can share some innovation stories from the past with students so that they can learn creativity by example.

- Experience failing: Students should not be afraid of failing because they can learn from their mistakes.

- Encouraging risk: Even though risk-taking is considered a personality trait it might be hard to encourage it, but educators should not discourage it. Risk-taking enables people to try new things (Piirto, 2011). Sternberg (2007) suggests encouraging risk taking among students. This can only be done by not punishing them for their mistakes. Runco (2007) suggests experimenting or trying an unusual way for finding new potential solutions. Sahlberg (2009) mentions the requirements of "making risk taking more common, and "making being wrong an acceptable norm" for creative thinking in schools (p. 344).

- Variety of answers: Educators should motivate students to search for more than one solution.

- Motivation: Educators can foster students' interest, so that they become more curious about the subject that motivates them internally. Grades also help in motivation.

- Owning the learning: If students feel they have control over their learning process they reveal more creative ability (Kazerounian & Foley, 2007).

In addition to these Maxims of Creativity, Richards (1998) suggests doing a series of activities to emphasise creativity in an engineering process: Immersing yourself in the problem, generating lots of ideas, using representation tools like brainstorming, sketches, playing with ideas, not being afraid of being different, being open to new ideas, relaxing, reflecting and having fun. Educators "must encourage ways of thinking, perceiving and evaluating information which support creativity and innovation" (Richards, 1998, p. 1038).

Wang (2007) believes that a person who wants to be creative needs to find out connections between different areas because ideas may rise from unexpected sources. Others explain this as using "analogies" (Dick, 1985; Runco, 2007). A most powerful and applicable tactic for creative thinking according to Runco (2007) is "shifting perspectives". In addition to other approaches, "humour" (McFadzean, 1998), "fantasy" (Dick, 1985) and "play" (von Oech, 1998) are believed to help look at things from different perspectives.

2.3.7 Creativity Blockers

There are also several studies about the blockers to creativity. Amabile (1998) is concerned that creativity "gets killed" much more than it gets supported. Treffinger et al. (2000) lists some myths and misconceptions about creativity that might obstruct creative thinking. Since people think creativity is a natural talent, some believe they can never be a creative person. Others think creativity is happening mysteriously with a muse or a magical inspiration, which makes it supernatural and not teachable.

Another misunderstanding is to relate creativity with some special disciplines, such as fine arts (Gurteen, 1998). Plucker et al. (2004) notes that the belief is people are born as creative or not creative. If one accepts this perception, there will be no effort to be creative. Some people think that being creative is like being crazy, eccentric or mad. The fine line between "genius" and "insane" has been a major discussion for years (Treffinger et al., 2000). von Oech (1998) summarises the creativity blockers in education as focusing on the one right answer, thinking an idea is not logical, always following the rules, trying to always be practical, not playing with the ideas and fearing to think about the things that are not in someone's area.

Kazerounian and Foley (2007, p. 762) declare "creativity is not valued in the contemporary engineering education", by summarising "barriers to creativity in engineering education". Thinking engineering is a "serious business" misleads engineers to "be accurate, not creative". There is a belief that creativity is leading to "chaos and disorder" and therefore it is not preferred. Creative behaviour might “contradict or violate academic standards”, which are important results of years of experience.

Liu and Schonwetter (2004) summarised the blocks to creativity and how to remove them, which is given by a table in Zhou’s review paper (2012c):

- “Fear of the unknown”: Students prefer to avoid unclear situations.

- “Fear of failure”: Students prefer not to take any risks. Gurteen (1998) agrees that fear is a block on creativity; such as the fear of “getting it wrong, making a fool of oneself”. Because of fear of failure, some students hold themselves back for not appearing incapable in front of the others (Masi, 1989).

- “Reluctance to exert influence”: Students hesitate to say what they believe.

- “Frustration avoidance”: Students give up too soon in case of facing any obstacles to avoid the discomfort.

- “Resource myopia”: Sometimes students cannot see their own strengths.

- “Custom-bound”: Students might depend on the past or customs too much, which negatively affect their development.

- “Reluctance to play”: Students resist playing around or experimenting (Zhou, 2012c). They tend to behave very seriously in formal meetings and they ignore playing, which is “an important learning method” (Campbell, 1985). There is also a belief that engineers cannot take risks like artists or musicians, because they might cause loss of lives, as they are building automobiles or bridges (Kazerounian & Foley, 2007). Gurteen (1998) agrees that seeing creativity as “a serious analytical task” inhibits creativity.

2.3.8 Creative Tools and Methods

Many tools and methods are used during the creative problem-solving process. A review of mostly used creative techniques in an engineering field is given in this study.

Chulvi, Sonseca, Mulet, and Chakrabarti (2012, p. 1) define design methods as "a series of procedures, techniques, aids or tools for designing". "Creativity methods are taught as a way to set the imagination free" (Zemke & Zemke, 2013, p. 456). Felder and Silverman (1988) believe the most important factor for the tools to be effective is "preparation" and "repetition". Chulvi et al. (2012) suggest applying the methods first with "short exercises that are not related to the actual problems". Then, the second step should be "solving the problem by applying given design method". This way of teaching the creativity tools is like Fender suggested. Torrance (1977) suggests "warm-up" sessions for creative activities too.

The literature classifies various creative thinking techniques used in a higher education level. McFadzean (1998) classifies problem-solving techniques into three parts:

- "Paradigm preserving techniques" that do not cause any change in perspective,
- "Paradigm stretching techniques" that stretch problem space boundaries by introducing new elements and relations, and
- "Paradigm breaking techniques" that entirely encourages looking at things with a new perspective (p. 311).

This section overviews the creativity tools described by previous literature (Lau et al., 2009; Thompson & Lordan, 1999; Liu & Schoenwetter, 2004; Zhou, 2012c) and summarises it in three headings:

- Tools for idea generation

- Tools for changing the perspective

- Tools for logical thinking

2.3.8.1 Tools for Idea Generation

The following tools are used for generating ideas without any input or stimulative.

- **Brainstorming**

Osborn first introduced brainstorming in the 1960s with the aim of stimulating the production of creative ideas during problem-solving processes. Within time, it has become a very popular tool (Simonton, 2000). A group of people come together and think of various ways of solving a problem (Anderson, 2013). According to Zhou (2012c) brainstorming made a big effect in problem-solving activities in the real world and it shows the best results in a group practice. Brainstorming helps to generate many, various or unusual solutions to open ended problems (Treffinger et al., 2000). Brainstorming is the favourite method of engineering design instructors and it is easy to administer (Court, 1998) as the guidelines are also easy to follow (Thompson & Lordan, 1999, p. 28).

Zhou (2012c) describes Osborn's brainstorming rules: By ruling out criticism any idea is welcome, no matter how crazy or unrealistic it is. By welcoming freewheeling discussion, a variety of ideas are generated without any judgment. Quantity eventually leads to quality, by combinations, improvements and by listening to others' ideas participants build new ideas based on each other's' input (Zhou, 2012c). Thompson and Lordan (1999) think the more ideas that are generated the better the solutions. However, Ferguson (1993) warns that creating many ideas does not necessarily bring good ones.

Although it has been "one of the most popular and effective creative-thinking methods" for years and helps to create a large amount of ideas, the disadvantage of brainstorming is its insufficiency in generating the best solution for a problem (Lau et al., 2009). Individual brainstorming is more efficient, as it allows people to come up with more and better-quality ideas when compared to group brainstorming (Mind Tools, 2015; Plucker et al., 2004). Due to the inefficiency of the brainstorming technique there is a shift to the use of other tools such as 6-3-5 and C-Sketch. (White et al., 2012).

- **6-3-5 Method**

The 6-3-5 Method is "a modified brainstorming technique" (White et al., 2012, p. 14) done individually. It is a "written rather than verbal idea generation process" and it is especially helpful when the team is under the dominance of certain participants, because it allows everyone equally to share ideas (Silverstein, Samuel, & DeCarlo, 2009, p. 111).

In the 6-3-5 method, 6 participants are expected to develop 3 concepts per person in 5 minutes of silent individual brainstorming. Then they pass their concepts to their nearest neighbours. Each participant reviews the concepts to add any modifications or enhancements to the original concepts. Every five minutes the rotation renews until the original concepts are returned to their original authors. All the activities are done without talking. Finally, they review the concepts together (Genco et al., 2012; Oman & Tumer, 2010).

- **C-Sketch**

In the C-Sketch method each member in the team draws one idea on a blank sheet of paper and then it proceeds like the 6-3-5 method and each sketch is circulated around (Dym et al., 2014). Participants exchange the sketches in silence and then communication is done after the rotation is completed (Genco et al., 2012). According to Dym et al. (2014) the nature of thinking is realised through sketching and they argue that therefore the C-Sketch method is appropriate for the mechanical engineering design area.

- **PNI Method**

The PNI method has been developed by de Bono (1990) and stands for Positive, Negative and Interesting. This method is used after generating an idea. First people write or say the things that are positive about the design solution, then they write or say negative things about the design solution and then the interesting things. Which makes participants not only think about the positive and negative things but also the interesting aspects (de Bono, 1990) about a design solution and that is where people can discuss and question creativity.

2.3.8.2 Tools for Changing the Perspective

Design heuristics are "intended to help designers explore solution spaces by specifically guiding them to generate non-obvious ideas that are also diverse from one other" (Daly et al., 2012a, p. 464). They help engineering designers generate various possible solutions. When designers are fixated on a particular solution, heuristics can help in creating different ideas (Daly et al., 2012a). The tools summarised here gives some heuristics or keywords to shift people's perspective.

- **Synectics**

Synectics is “a sophisticated and highly systematic form of problem-solving which incorporates the rules of brainstorming” (Thompson & Lordan, 1999, p. 24). Analogy and metaphors are used to examine the problem to find a better solution (Thompson & Lordan, 1999; Lau et al., 2009). What distinguishes Synectics from Brainstorming is that the participants work together on a particular solution instead of generating many ideas. Therefore, a Synectics session is longer than a Brainstorming session (Cross, 2008; Dinsdale, 1991). It not only helps “generating novelty, but also seeing connections between things not normally regarded as connected” (Cropley, 2015a, p. 247).

- **SCAMPER**

SCAMPER is another method, developed to generate novel ideas, and is an acronym for: “Substitute, Combine, Adapt, Modify/ Magnify/Minify, Put to other use, Eliminate, Reverse/Rearrange” (Park & Seung, 2008). The belief is that “creating something novel is simply changing something that already existed” (Lau et al., 2009, p. 76). It helps designers evolve their existing solution by asking a set of directed questions which should be used as triggers to generate ideas. It is highly effective when there is an idea that needs to be developed (Silverstein et al., 2009). SCAMPER offers more specific guidelines in creating ideas when compared to brainstorming (Daly et al., 2012b). Chulvi et al. (2012) found out from their experimental study that even though SCAMPER is accepted as an intuitive method it is not as extreme as brainstorming. It is somewhere in between brainstorming and functional analysis (Chulvi et al., 2012).

- **Six Thinking Hats**

In order to cut across routine patterns that the brain follows, people can use deliberate techniques. The Six Thinking Hats system is a convenient way of switching thinking and enhancing creativity (de Bono, 1995). The system has been used in schools and in business around the world. The Six Thinking Hats system is practical and easy to learn and use (de Bono, 1996). It encourages participants to come up with many alternatives that were not considered before (Park & Seung, 2008). There are six metaphorical hats, each of which covers different things, and the person needs to put on and take off these hats to change the way s/he thinks (de Bono, 1995).

- **Random Words**

The random words method, also known as "random input" is considered as the simplest of all creative techniques, suggested by de Bono (1995). When there is a need for a new idea for some situation, a random word is introduced (Lau et al., 2009; de Bono, 1995). It is "an excellent way of getting new perspectives on a problem" (Mind Tools, 2015). Researchers (Anderson, 2013; Felder, 1988) describe this method as forcing participants to think about their problems in a new way by making unusual connections between the problem and a set of random words. Lau et al. (2009) link this method with "free association".

2.3.8.3 Tools for Logical Thinking

de Bono (1993) mentions one misbelief that releasing the mind will bring on creative ideas. Freethinking is valuable but it does not necessarily bring sudden creative ideas (de Bono, 1993). Therefore, students must also be supported with more logical tools.

- **Morphological Analysis**

Morphological analysis is a well-known analytical technique in engineering design. It works by dividing a problem into functions and sub functions, by preparing a chart, then generating alternative ideas for each function and finally evaluating possible combinations by mixing and matching (Treffinger et al., 2000; Oman & Tumer, 2010). The only difficulty with morphological analysis is choosing in between the best configuration (Thompson & Lordan, 1999; Zhou, 2012c). If the idea generation is done correctly a morphological analysis table helps generate many options to be considered (Cropley, 2015).

- **TRIZ**

Another method used in engineering design is TRIZ, which is a Russian expression meaning "theory of inventive problem-solving". It is a concept generation process, using previous knowledge from past inventors (Ogot & Okudan, 2006). In TRIZ, the most important sources are "patent and technical information" (Savransky, 2000, p. 24). It is believed to solve technical problems and seen as essential for creative engineers in problem-solving (Savransky, 2000). It also uses heuristics to bring solutions for a problem. TRIZ was the most popular creative tool in the Soviet Union while brainstorming was the most popular creative tool in Western countries (Savransky, 2000). TRIZ has been studied increasingly and integrated in design curricula (Ogot & Okudan, 2006).

2.3.9 Conclusion

This section reviewed creativity in engineering, first by defining and describing the nature of it and then examining if creativity can be taught and learned. It analysed the components of creativity in 4Ps, it summarised creativity assisters and blockers and finally it overviewed the tools and methods used for creative thinking. The last section will review creative pedagogy in engineering education.

2.4 CREATIVE PEDAGOGY IN ENGINEERING EDUCATION

Many researchers argue that education has a role to play in relation to creativity (Amabile, 1983, de Bono, 1995; Cropley, 2006; Lin, 2011). Such education gives students the opportunity to engage in creative activities by expanding their knowledge and experience, which consequently enhances their creative success (Williams et al., 2010). Richards (1998) believes that original creative work has to be part of every engineering course. It is regarded as a powerful tool in the design process, but still, few courses encourage creativity in the standard engineering curriculum (Richards, 1998). Engineers' success depends on the "level and amount of creativity and innovation they exhibit in developing sustainable engineering concepts, components and systems" (Panthalookaran, 2011b. p. 612).

This section first analyses creative pedagogy in engineering education, the reason why it is required and different approaches to teaching creativity. It discusses the assessment of creativity in an engineering context. Then it focuses on different types of learning in engineering and delves further into problem / project based learning.

2.4.1 Creative Pedagogy

From an engineering perspective, creative pedagogy needs to consider some issues for overcoming current barriers: "Facilitating staff development, providing creativity in training to students, encouraging group work and building a creative learning environment" (Zhou, 2012a, p. 352). With a similar view to Zhou (2012a), Lin (2011) agree that creative pedagogy can be studied from three perspectives:

1. “Creative teaching”
2. “Creative learning”
3. “Teaching for creativity”

The first perspective is about the way the instructors teach and their approach, the second one is about the way the students learn and also about creating a stimulating environment that is supportive to learners’ motivation, while the third perspective is about the tools and methods used during teaching (Lin, 2011). Craft (2003) also argues that creative teaching, teaching for creativity and creative learning are all distinctive aspects of teaching creativity that need to be studied. Therefore, this section investigates all three.

2.4.1.1 Creative Teaching / Instructor for Creativity

The educator perspective has a significant impact in fostering creativity. It covers an instructors’ attitude, their approach to enhance creativity, the kind of questions they ask of students and the type of relations they build with their students. Researchers argue that a student’s learning depends on his ability, his prior preparation, his learning style and also the educator’s teaching style (Felder & Silverman, 1988). Creative teaching inspires students’ imagination. It involves imaginative, dynamic and innovative approaches (Lin, 2011). If students are expected to be creative, instructors have to model creativity for them and facilitate the learning process. But it cannot be done by loading them only with knowledge (Sternberg & Lubart, 1996; Hmelo-Silver, 2004).

Teacher and student interaction is significant in a design-studio setting, as design education is based on an apprenticeship process (Ferreira, Christiaans and Almendra, 2014). Goldschmidt et al. (2010), looking from an architectural point of view, believe the instructor should behave as a coach or facilitator communicating with the students, as it is the most productive role in the design process where the instructor guides and supports the student to develop their work and their abilities. A traditional teacher centred approach has turned into a student centred approach, where teachers just facilitate and support students (Williams et al., 2010).

To design an engineering curriculum all engineering instructors are required to be able to apply modern educational theory and “adopt humanistic attitudes”, such as being more accepting and tolerant (Törnkvıst, 1998). Zhou (2012b) believes a positive attitude toward creativity helps individuals engage in creative efforts.

When applying new thinking tools and methods in class the facilitator is as important as the tools (Zhou, 2012c). The facilitator creates the atmosphere for idea generation, selects the most appropriate technique for the participants and sets the context (Baillie & Walker, 1998). S/he is responsible for teaching how to recognise and remove creativity blockers (Liu & Schonwetter, 2004). Therefore, teacher-training programs must be developed to improve the capacity of teaching in creativity with new approaches (Panthalookaran, 2011a; Baillie & Walker, 1998). Horng et al. (2005) suggest equipping educators with creative teaching strategies and inviting experienced creative instructors and professionals to share their experiences in developing creativity in educational institutes.

Because of the inefficiency of teachers’ explanations about the problem-solving process, engineering students face the difficulty of connecting and applying what they have learned in technical units (Wedelin & Adawi, 2014). Torrance (1977) argues that teachers must find their own ways of teaching, experimenting for facilitating creativity among students. In short, instructors need to learn how to conduct the units for enhancing creativity.

2.4.1.2 Creative Learning / Environment for Creativity

Although pedagogy focuses on the educator, the learning environment is also important. The general atmosphere in the classroom, the physical and psychological aspects of the study area play a crucial role in fostering creativity. If it is not permissive and supportive creative skills might not appear (Runco, 2007). Previous studies hold a light on how the structure of the units affect students’ creative development (Rhodes, 1961; Sternberg & Lubart, 1996; Treffinger et al., 2002).

Davies et al. (2013) identify the characteristics of the environments and conditions that are most effective in promoting creative skills: Using the time and class in a flexible way, providing enough materials for students, encouraging extra-curricular activities, building respectful relationships with the students, promoting collaborative work and having nonprescriptive planning. Morin, Robert, and Gabora (2014) highlight the need for new classrooms that fit the needs of a creativity class across engineering programs instead of traditional classrooms. Plucker et al. (2004) support this idea by indicating that current classrooms do not help fostering creativity because they lack originality. Educators can create a suitable classroom atmosphere for students that is conducive to creativity by supplying a variety of materials or allowing students to arrange the room and reconfigure the furniture so that they can exercise and reveal their creative abilities (Welkener, 2013; Felder, 1988). That is what students demand: A learning environment in which they can both individually reflect themselves and interact with the others for group creativity (Zhou, 2012b).

Arciszewski (2014) outlines the importance of hands-on experimentation in engineering teaching. Like Thompson and Lordan (1999), Mitchell (1998) also recommends providing a cooperative and safe learning environment for engineering students, where they are supported, encouraged and expected to experiment with ideas and concepts for creative results.

According to Stouffer et al. (2004), there is not a right way to approach creativity; as long as there is an atmosphere encouraging innovative and uncensored thinking, novel solutions can be acquired. Panthalookaran (2011b) thinks that "by creating necessary ecosystem and providing sufficient opportunities, the students will naturally develop engineering creativity and technical innovation skills" (p. 616).

2.4.1.3 Teaching for Creativity / Tools for Creativity

Creative teaching is coming up with innovative ways of teaching to challenge students by using new learning strategies and exploring new possibilities (Lin, 2011). Santamarina (2003) summarizes many ways of teaching creativity through an engineering curriculum: Open-ended assignment questions, discussion sessions, varying the class format, self-analysis, team-building exercises, class experiments, promoting a creative attitude, allowing flexibility in assignments, speed processing, encouraging free associations and divergent thinking, assigning daily time for creativity, reviewing the creative thinking process through historical examples, reviewing inspiring articles, encouraging in-depth critical thinking, motivating students in problem-solving, team working, encouraging networking and collective creativity. Similarly, Stouffer et al. (2004) suggest engineering courses can be improved by using creative thinking approaches such as brainstorming, imagination, drawing, developing a questioning attitude, or thinking alternatives.

Using creativity tools is a way of teaching creativity. They provide students with some basic methods to develop their creative thinking. Engaging, activating and encouraging creativity in the classroom is classified by Treffinger et al. (2002) in three levels: Using basic thinking tools, practising problem-solving processes, and working with real-life problems.

2.4.2 Why do Engineers Need More Creativity and Creative Thinking?

Engineering will always do routine problem-solving. However, the 21st century requires more creative and novel solutions to new problems. In order to achieve this, engineers need to be as good with creativity as they are with technical knowledge (Cropley, 2015b). Although it can be challenging for engineering students, who are more comfortable working with defined parameters and values, to learn creativity, it is necessary for engineers and it must be taught (de Vere, 2009). Even though some students have natural creativity, engineering educators can have an influence too (Mitchell, 2006). The challenge is to teach creative skills in design subjects to engineering students, who have cognitive hindrances such as a “lack of design language, an unstocked repertoire, the unreliability of the imagination, and fixation throughout the design cycle” (Zemke & Zemke, 2013, p. 457). There is a consensus among researchers (Cropley & Cropley, 2000; Churches & Magin, 2001; Pappas, 2002; Santamarina, 2003; Kazerounian & Foley, 2007; Williams et al., 2010; de Vere et al., 2010a; Zhou, 2012a) that fostering creativity and introducing creative thinking in engineering courses is still a challenge.

There are many reasons why creativity needs to be developed in engineering education. First of all, creativity and innovation are counted as central aspects to design and engineering (Petroski, 2002). Engineers need to be educated to be creative thinkers to further evolve the legacy of engineering ingenuity (Kazerounian & Foley, 2007). A most important reason to enhance creativity in engineering education is to get the benefit in terms of innovation in schools (Runco, 2007). If engineers want to achieve innovative solutions they must have creative skills (Cropley & Cropley, 2000; Felder, 1987). Future engineers are expected to have technical capabilities, to adapt to a continuously changing environment and are also expected to think creatively while solving complex problems (Pierrakos et al., 2008). Creativity is an important part of engineering educational development that will serve a basis for students' future role in industry (Court, 1998). However, it is not very easy to teach because of the different backgrounds and contexts of educators (Berglund et al., 2011).

Creativity is required throughout the development of a product, not just at the early concept stage (Froyd et al., 2012). The successful products in the market are the most creative ones (Oman & Tumer, 2010), because "creative design is the core of product innovation" (Li et al., 2006, p. 2013). Charyton and Merrill (2009) consider creativity essential, rather than just being "an accessory in engineering". Cropley (2015a) describes creativity and engineering as the "two sides of the same coin" (p. 22). de Bono (1993) explains the need for creativity in two specific situations: First, when there is a need for a new idea or concept, in other words when "creativity is the only hope" (p. 20). Second, even when there is not an urgent need for a new idea creativity can still can provide new perspectives, advantages and benefits (de Bono, 1993).

In order to enhance creativity in engineering education the effects of beliefs about creativity must first be understood.

2.4.3 The Impact of Beliefs in Education

Beliefs have an important role in instructors' teaching practices and in their pedagogical decisions (Richardson, 1996; van Driel et al., 2007; Henderson et al., 2011). Richardson (1996), after analysing the literature, argues that a person's actions are driven by his attitudes and beliefs. They are important to decipher educators' thought processes and classroom practices. Personal experiences about education influence the development of beliefs about teaching. However, the intimate relation between beliefs and knowledge is not much evident in education literature. Richardson (1996) draws attention to the idea that beliefs held by people, like knowledge, are accepted as truth. Many scholars think that beliefs are very difficult to change (Richardson, 1996). Karataş, Bodner, and Ünal (2016) conducted questionnaires with first year engineering students and found out that "students' beliefs have strong influence on what they value in a classroom situation, what they attend to in class, and how they choose to study for a course" (p. 1). There is an interactive relationship between beliefs and actions: "Beliefs are thought to drive actions; however, experiences and reflection on action may lead to changes in and/or additions to beliefs" (Richardson, 1996, p. 104).

Henderson et al. (2011) reviewed the previous literature which argued about the role of the instructor in the implementation of Problem/Project Based Learning (PBL). Henderson found that a change of strategy is needed which involves encouraging teachers to develop and use new teaching methods and practices (Henderson et al., 2011). Kelchtermans (2009) claims that teachers' perceptions change with the cultural, social and environmental structure. Therefore, changes take a long time in teaching, because in order to make changes in an educational field, first the educators' beliefs must change (Quinlan, 2002).

2.4.4 Different Approaches in Fostering Creativity among Engineering Students

There have been a number of longitudinal studies on the methods of enhancing creativity in engineering education. Some researchers experimented with the idea of teaching creative thinking skills separately from the engineering subjects, as an extra hour or a day or as a workshop (Panthalookaran, 2011b; Adams & Turner, 2008; Anderson, 2013; de la Barra, de la Barra, & Urbina, 1997; Zhou, 2012b; Gerber, Olson, and Komarek, 2012). Some believe that teaching creativity separately gives better results (de Bono, 1990) and prefer to design new subjects, focusing solely on creativity (Cropley & Cropley, 1998; Warsame et al., 1995; Richard & Carlson-Skalak, 1997). However, the majority of the literature (Charyton & Merrill, 2009; Kazerounian & Foley, 2007; Stouffer et al., 2004; Mitchell, 2006) has a holistic approach and believes that creativity and creative thinking should be embedded in the subjects and be inherently a part of the whole engineering curricula. In addition, some believe that the whole curriculum needs to change (Baillie, 1998) because methods of teaching creativity are different from methods of teaching engineering. Lim et al. (2014) mention this debate about enhancing creativity by "standalone subjects" or "integrated units" in the curriculum. They argue that separately designed units might have better impact; however, there is the issue of limited time. Pappas (2004) highlights the advantage of an integrated approach as it preserves the teaching time for technical subjects. However, de Bono (1990, 1993) believes in the direct teaching of creative thinking skills. On the other hand, implementing a newly designed creativity unit in the curriculum requires additional faculty effort. Therefore, Lim et al. (2014) suggest fostering creativity throughout the curriculum by systematically redesigning the curriculum.

Morin et al. (2014) argue that learning things in other domains is important in developing a deeper understanding of a certain subject. Additional units to the curricula develop students' awareness of the engineering profession (Baillie, 1998). Researchers who design additional units for engineering education are aiming to encourage students to explore creativity in engineering (Budnik & Johnson, 2012), teaching students "how to think rather than what to think" (Adams & Turner, 2008, p. 5), influencing student perceptions about design and product development (Vukasinovic, Fain & Dukovnik, 2011), or highlighting the importance of "problem-solving in the engineering curriculum" (Wedelin & Adawi, 2014, p. 49). One disadvantage of addressing creativity separately to the curriculum is that it might take longer to show its effect. Baillie and Walker (1998) suggest seeing creativity as inherent in the learning process rather than addressing it as an addition.

Debate continues as to when best to embed creativity skills development in the curriculum. Some researchers (Dym et al., 2005; McMasters & Ford, 1990; Burton & White, 1999; Richards & Carlson-Skalak, 1997; Forbes, 2008; Warsame et al., 1995; Baillie, 1998) highlight the first year of engineering education, as these authors believe that neither creativity nor design can be taught in one subject, and that it is important to introduce concepts early in the engineering education framework. On the other hand, some researchers (Dutson et al., 1997) emphasize the importance of introducing it in the final year design subjects to better prepare graduates for industry. But other researchers (Churches & Magin, 2001; Liebman, 1989) criticize the efficacy of final year design subjects in the engineering curriculum for teaching creativity, arguing that design and creative skills cannot easily be learned in a single semester. Such teaching should not be limited to one or two classes but dispersed throughout the curriculum. However, it is a challenge to design an accredited engineering curriculum that incorporates all these aspects (Anderson, 2013).

There are many universities that are trying to overcome the lack of creativity in engineering curricula by various approaches. Table 2.1 shows the different approaches for enhancing creativity in engineering design education taken from the papers published or presented in the last two decades.

Table 2.1 Different approaches for enhancing creativity in engineering design education

UNIVERSITY	COURSE	WHAT HAS BEEN DONE	WHEN / HOW LONG	NATURE OF THE ACTIONS	HOW HAS BEEN DONE / USED TOOLS AND TECHNIQUES	CONCLUSION REMARKS	THE AUTHORS	YEAR
Prairie View A&M University	All engineering majors	Creative Engineering design sequence. 1st: Emphasizes solid modelling, drawing, engineering specifications. 2nd: Design unit requiring students to use the basic principles gained.	1st year 2 semesters	New subjects	Participative learning method, teamwork, solution to a real-life engineering problem. Problem identification, preliminary ideas, design refinements, design analysis, implementation.	Increased the creativity and motivation of the students and helped their studies. Retention from 1st to 2nd year increased 50%, highly successful.	Warsame et al.	1995
University of Canterbury	Chemical Engineering	A subject on problem-solving techniques supported by interactive computer instruction: "Strategies for Creative Problem-Solving Techniques"	3rd year	Integrated in design teaching	9 one-hour sessions: "1. An introduction to problem-solving, 2. Problem statement definition techniques, 3. Brainstorming, Methods of solution generation, 4. Situation analysis, 5. Problem analysis, 6. Decision analysis, 7. Potential problem analysis, 8. Planning, 9. Evaluation".	Students appreciated the problem-solving approach. Working in pairs found to be beneficial.	Allen et al.	1996
University of Virginia	Dept. of Mechanical, Aerospace, and Nuclear Engineering	As part of a major revision of the first-year curriculum: "Engineering Design" unit.	1 semester	A new subject	Each week 50 minutes class, 90 minutes workshop: Design projects and case studies	It has been valuable experience for students and it was successful in achieving its goals	Richard & Carlson-Skalak	1997
Universidad Tecnica Federico Santa Maria	Engineering courses	Designed 2 workshops in a creative teaching environment by using face-to-face cooperative learning techniques and divergent thinking methods	1st year 1 semester 1 session/w	Extracurricular voluntary activity	Divergent thinking methods	Students who took the workshops showed more effective learning and creative problem-solving strategies compared to the ones working under traditional schemes.	de la Barra et al.	1997
University of South Australia	Engineering	Implementation of an undergraduate subject in Bachelor of Engineering degree	N/A	A new subject	Four components: Lectures about definition and importance of creativity, the role of the engineer, creativity in problem-solving and blocks to creativity, Educational counselling sessions, Case studies focusing on creativity and innovation, Creativity project to develop students' skills.	Lectures helped to develop a theoretical creativity model. Counselling provided guidelines for improving skills. Creativity project allowed students to participate in a creative ability in a supportive environment.	Cropley & Cropley	1998
Sydney University	Mechanical Engineering	A new subject was designed "to enhance the thinking skills of the engineering students": "Professional Engineering"	1st year	An extra subject	A variety of activities encouraged "group work, discussions, debates, role plays, competitions, interviews, presentations, communication exercises, industrial visits".	The seminar program is believed to have long term benefits to students in terms of developing creativity and innovation skills.	Baillie & Walker	1998
University of Alaska Fairbanks	Department of Civil and Environmental Engineering	Methods for teaching design to engineering students	1st year	Integrated in the subjects	Methods: Reverse engineering, Creating something useful, Full Scale Project, Small scale project, Case studies, Competitions, Non-profit project, Local project.	"Teaching freshman design is the best way to get students with the design process and encourages them to begin applying its concepts".	Burton & White	1999
University of Nevada	Mechanical Engineering	Focused on product development, team skills and technical reporting.	1st year	Integrated in the subject	Worked in team based exercises with hands-on approach. Lego were used to teach design and creativity.	Student enrolment has more than doubled. Lego provided excellent medium for teaching creativity.	Wang	2001
University of Toledo	Engineering	Introduction to engineering design subject with TRIZ method	1st year 1 semester	Integrated in the subject	First project was traditional idea generation method, second project was TRIZ.	TRIZ made easier to generate feasible concepts to design problems. Number of unique design concepts increased in TRIZ teams in comparison to non-TRIZ teams.	Ogot & Okudan	2006

UNIVERSITY	COURSE	WHAT HAS BEEN DONE	WHEN / HOW LONG	NATURE OF THE ACTIONS	HOW HAS BEEN DONE / USED TOOLS AND TECHNIQUES	CONCLUSION REMARKS	THE AUTHORS	YEAR
University of Northampton	Engineering courses	One-hour sessions per week	1st year 2 semesters	Extra hour	Analytical and creative techniques were used: Brainstorming, thinking aloud, meta plan, mindfulness training, meditation technique	Students believed they got better in problem-solving. The authors suggest to encourage PBL should in engineering students through use of a suitable classroom environment exercises.	Adams & Turner	2008
University of Massachusetts	Chemical Engineering	Teaching module that can be integrated into an introductory subject	1st year	Integrated in the subject	Brainstorming, Lateral thinking, Synectics were used.	Concepts that were introduced in the module helped students become more comfortable with open-ended problems.	Forbes	2008
Technical University of Madrid	Agronomic Engineer Technical School	Cooperative Project-based learning (PBL)	Final year	Integrated in the subject	Merging different methods: "Activities inside and outside classroom, lecture, group activities, cooperative learning, online and face-to-face tutoring, project exhibits, competition among teams".	Three advantages: "Training in technical, personal, and contextual competencies, Real problems in the professional sphere are dealt with, Collaborative learning is facilitated through the integration of teaching and research".	de los Rios et al.	2010
University of South Adelaide	Engineering	Theoretical lectures on creativity	2nd year 1 semester	Integrated in the curriculum	Lecture content were focused on learning about creativity and creative activity. Second element was to design novel and effective model of a wheeled vehicle.	The authors declared that "to teach students how to achieve creative designs, students must be informed about what is creative in their designs".	Cropley & Cropley	2010a
Rajagiri School of Engineering & Technology	Engineering & Technology	Hour of creativity in modules: A tailor made program to train the students of Bachelor of Technology	1st year	Separated, extra hour of creativity	Sessions included: Initialization session (mind freeing activities, oriental yoga), Problem-definition session, Brainstorming session and Evaluation session.	Accomplished to a great extent. The hour of creativity will remain as the practical session of the subject.	Panthalookaran	2011b
Aalto University	Health Technology Microbiology in MSc in Design Factory	2 hours/pw lectures and 3 hours/pw group work	MSc level 7 weeks	Integrated in the subject	Focused on "learning by doing, cooperation and team work": "Drawing, Legos, modelling clay, knitting machine, videos, movies, welding, electronic, music"	Enhanced students' understanding in difficult topics, development in confronting complex team work situations.	Nordstrom & Korpelainen	2011
University of Ljubljana	Faculty of Mechanical Engineering	A new unit in the curricula: "Product Design and Development"	N/A	A new subject	Problem-solving process: Product and market analysis, product development, CAD modelling.	There has been an improvement in success, by using motivational approaches, but the unit needs additional improvement.	Vukasinovic et al.	2011
The Royal Institute of Technology and Stanford University	The Swedish Product Innovation Engineering Program	Workshop program to establish change in mindsets	5 days	Extra-curricular	Design thinking lecture, Innovation workshop, teamology workshop, instrumenting and measuring innovation and site visits to Cars-lab, IDEO, Google and UC Berkeley.	Resulted with the understanding of proposing any kind of change in in the mindset requires big effort.	Berglund et al.	2011
Swinburne University of Technology	Mechanical Engineering	Projects in Machine Design and Engineering Management that required documentation of a creativity tool to solve an identified problem.	3rd year 1 semester	Integrated in the subject	List of creativity tools were provided for problem-solving (6 hats, Morphological Analysis, Synectics)	Resulted with the understanding of that "engineering students need to be taught more than creativity", such as how to combine creativity with their knowledge of engineering theory.	Abdekhodaee & Steele	2012
Valparaiso University	College of Engineering	3 days creativity instruction: "Inspiring Creativity"	NA	Separated sessions within a subject	"Team teaching approach": Educators from inside and outside of the faculty did a site tour, brainstorming sessions, engineering scavenger hunt in a theme park.	There has been an "improvement in students' confidence, their creativity perceptions and their ability to use and lead a creative process"	Budnik & Johnson	2012
Brigham Young University	Technical Engineering: Manufacturing Engineering, ID, IT	Instructional program: "Innovation Boot Camp"	2 days	Extra-curricular	Principles of innovation through solving real problems: "Idea finding, idea shaping, idea defining, idea refining, idea communicating".	The curriculum encouraged students to work in multidisciplinary groups by providing them a hands-on experience.	West et al.	2012

UNIVERSITY	COURSE	WHAT HAS BEEN DONE	WHEN / HOW LONG	NATURE OF THE ACTIONS	HOW HAS BEEN DONE / USED TOOLS AND TECHNIQUES	CONCLUSION REMARKS	THE AUTHORS	YEAR
University of Massachusetts	Mechanical Engineering	Comparative experiment between 1st and 4th year	3 semesters	Integrated in a design subject	Innovation enhancement techniques then 6-3-5- method.	First year students generated more original concepts, but there was no difference in quality. Need for additional studies on innovation capabilities during design.	Genco et al.	2012
Northwestern University	Design for America, studio	Extra-curricular design based learning model in interdisciplinary student-led studios anchored in universities	6 weeks Summer studio	Extra-curricular	Students practiced innovative solutions to authentic, pro-social, and local challenges by blending elements from "project-based learning, design-based learning, service learning and situated learning to provide hands-on innovation".	The model positively influences students' skills and beliefs in ability in innovation related tasks.	Gerber et al.	2012
University of Moratuwa	Computer Science and Engineering	"Software Engineering Project" unit is designed.	3rd year 1 semester	A new subject	The unit started with a workshop by asking 'if only' questions to students. Brainstorming was done. Former students were invited. Then students were expected to defend their ideas in front of their lecturers.	It has been successful, and positive changes were observed in students' approach. Students' level of confidence increased in software development.	Weerawarana et al.	2012
Lulea University	Mechanical Engineering	A workshop to improve students' creative and sketching abilities	6 hours in 2 days	Extra hours	Educators from Innovation and Design Department held a workshop designed in five steps: "1. Warm-up, 2. Speed exercises, 3. Readability, 4. Creative exercise, 5. Reflection".	Simplifying the tasks and focusing on sketching as a creative tool improved the outcome of students' projects.	Öhrling et al.	2012
Swinburne University of Technology	Product Design Engineering	Sketch fest: Use of free-hand drawing	Final year	Integrated in the subject	Open ended projects allowing quick ideation sketching.	Students reported that their sketching skills are increased.	de Vere et al.	2012
Aalborg University	Medialogy	A creativity training program is carried out.	5 days	A separate program	Training involves mix of lectures, workshops and discussion sessions: Theory of creativity, idea generation methods, brainstorming, checklist exercises, mind mapping.	Program was successful in terms of gaining project work skills, creative concepts and confidence of being creative and understanding of creativity. However, only five days of training was not enough for learning skills in PBL.	Zhou	2012b
University of Arkansas	Interdisciplinary (Engineering, Business, Psychology, Art)	3 subjects developed: Strategies for Innovation, Design Skills, Innovation Project	A subject per semester	New subjects	"Global and Specific Abstractions, Random Words, Mind mapping, SCAMPER, Rephrase the Problem, Multiple Perspectives, Force Field Analysis, Making Novel Combinations, and Da Vinci's Technique".	"Design an innovation skills should not be limited to one or two classes, but dispersed through the curriculum".	Anderson	2013
Chalmers University of Technology	Software Engineering	Weekly modules: A subject in mathematical modelling and problem-solving process.	2nd year 1 semester	A new subject	Focus on problem-solving learning: 30 realistic problems were designed to be solved in pairs in a workshop setting under Socratic supervision.	Students' modelling and problem-solving skills developed. This kind of subjects or teaching should be present in the engineering education.	Wedelin & Adawi	2014
Polytechnique Montreal	Engineering School	12-hour workshop: "Creativity yes we can"	PhD degree	A new subject	Class discussions, games, a few creativity approaches (Mind mapping, 6 Thinking hats, SCAMPER), warm up exercises. First, individual artistic project, then, group engineering project.	The presented training "could eventually become part of the curriculum of all engineering programs".	Morin et al.	2014
University of South Adelaide	Engineering	Introductory subject on engineering creativity: 1 h lecture, 1 h tutorial, 2 h practical activity every week	15 weeks	A new subject	Exercises related with creative thinking (such as Egg exercise, Spaghetti exercise)	A curriculum for engineering creativity was developed as an example.	D. Cropley	2015a

2.4.5 Assessing Creativity

Previous research shows that rewarding motivates learning (Torrance, 1977). Mitchell (1998) emphasizes the difficulty of defining and judging creativity. Due to ambiguity, students feel stress and dissatisfaction in the assessment of creativity (Williams et al., 2012). When assessing the creativity of a design it is suggested to rely on human judgement as there is no absolute criterion for creativity (Treffinger et al., 2002). Therefore, Mitchell (1998) suggests engineering educators do their own version of creativity definition. However, Cropley (2015a) mentions the difficulty of defining creativity in a practical and objective way due to its subjectivity. In order to teach students how to be creative, first the educators need to specify what creative is in their designs to use for assessment. Only then can an appropriate pedagogy can be developed (Cropley & Cropley, 2010a). The abstract nature and definition of creativity have caused debates over evaluating individuals' creativity since the 1960s. This is still is a concern (Oman & Tumer, 2010).

In addition to qualitative methods some researchers prefer quantitative methods to assess creativity. Shah et al. (2000) proposed four metrics to evaluate creativity: Novelty, Variety, Quality and Quantity. They evaluate these parameters for every function and then formulate the ratings into a holistic metric. Oman and Tumer (2010) examine the factors that affect creativity in the early stages of engineering design and look for quantified methods for assessing creativity and innovation in a first-year mechanical engineering unit. In order to decide whether an engineered design is successful or not Dym et al. (2014, p. 9) suggest using metrics set to assess a design's "objectives" and "function".

Takai (2011) suggests that in order to motivate students to look for creative ideas educators should assess the projects with both a creativity assessment and a numerical performance assessment. Yuan and Lee (2014), depending on their empirical study, argue the traditional qualitative judgements are subjective and insufficient and therefore they propose a creativity assessment formula. They suggest the use of a quantitative approach for assessment, adding that there needs to be more than one assessor for reliability. In order to minimise the human variables, Shah et al. (2000) suggest "randomisation", which means assigning designers to groups randomly at different times. Another suggestion is using the same assessment group for all the runs, so even though there is a human variable effect all the groups will be affected equally.

2.4.5.1 Creativity Assessment Methods

The assessment methods examined for this study are the relevant ones for engineering that are taken from journal papers.

After reviewing more than a hundred sources, Treffinger et al. (2002; 1998) prepared a list of "creativity characteristics": "Generating ideas, digging deeper into ideas, openness and courage to explore ideas and listening to one's inner voice". Daly et al. (2014) considered what Treffinger et al. (2002) provided from an engineering perspective and they agree that by breaking it down to cognitive components it is a clear and practical understanding of creativity. Similarly, Johri et al. (2009) highlight the multidimensional and complex nature of creativity. Therefore, a single instrument or measure is not enough to effectively assess creativity. Accordingly, the assessment plan needs to be structured to collect tracks of creativity in different ways. Treffinger et al.'s (2002) matrix of the characteristics for assessment are given in Appendix II. The assessment plan gives clues as to what and how to assess creativity. Johri et al. (2009) support using this structured matrix for assessing creativity in engineering students.

Cropley (2000) summarises a large number of assessment tools for measuring creativity and overviews creativity from product, process, motivation and personality perspectives. The most cited one is the CPSS (Creative Product Semantic Scale) which was developed by Besemer and O'Quinn in 1986. It measures product creativity by three scales: "Novelty" is the newness of the processes, the materials and the solution. "Resolution" is the functionality, usability and usefulness of the product. "Elaboration and Synthesis" are the visual attributes of the end-product (Christiaans, 2002). It has been used by many researchers (Takai, 2011; Chulvi et al., 2012) but some find it weak because of its vague definition of creativity (Childs, 2010).

Another well-known creativity assessment method is the Consensual Assessment Technique (CAT) developed by Amabile (1983, 1996). At the heart of CAT is to ask people whether a product is creative or not. It involves recruiting a judge panel made of experts in the field and expect them to rate the creativity of a product. The principle for the assessment is the "agreement among observers" (Cropley (2015a, p. 76). Christiaans (2002) depending on his empirical study argues that in the absence of fixed creativity criterion, assessment depends on subjective judgment. He adds that in design education "it would be helpful to rely on expert judges" (p. 53). On the other hand, Cropley (2015a) believes that there are practical issues with this method in engineering; "it is time consuming and expensive to assemble a panel of experts every time" to assess creativity (Cropley, 2015, p. 76).

Multi-Point Creativity Assessment (MPCA) is a newly developed (Oman, Tumer, Wood, and Seepersad, 2013, p. 78) metric for assessing product creativity, using similar criteria such as "original/unoriginal, well-made/crude, surprising/expected, ordered/disordered, astonishing/common, unique/ordinary, logical/illogical". Different from CPSS, MPCA considers judges' perceptions of creativity and calculate the weighted value for each criterion.

Oman et al. (2013) suggest Comparative Creativity Assessment (CCA) in which they combine "the theory behind the novelty and quality metrics" (p. 77) to help designers and engineers during the creativity assessment process. The authors (2013) claim that this new method is successful as it depends on original methods, but validation is difficult.

Torrance developed a test called Torrance Tests of Creative Thinking (TTCT), aiming to measure creativity within four areas: Fluency, Flexibility, Originality and Elaboration. It is one of the oldest and most widely used measurements for creativity by researchers and educators (Mahboub et al., 2004; Ibrahim, 2012). It is frequently used with children despite that it is believed to be suitable for all ages (Cropley, 2015a). In its application students are subject to pre and post-tests at the beginning and end of the course (Mahboub et al., 2004).

Charyton and Merill (2009) point out that psychology and engineering faculties have developed Creative Engineering Design Assessment (CEDA), which provides practical application in engineering education and has been shown to be reliable and valid (Charyton et al., 2011). CEDA assesses a person's design ideas expressed by sketching (Charyton & Merill, 2009). Its criteria for measurement are not very different from

TTCT, being fluency (quantity of solutions), flexibility (variety of solutions) and originality (novelty) in a design. Generating multiple solutions to a given problem is as important as coming up with a solution to the problem, because a productive creative process has an effect on the final product (Charyton & Merill, 2009).

Fudge, Strood and Agogino (2013) combine the human judgement metrics, which are dependent on human decision making, and the model-based metrics, which use a mathematical formula to calculate the creativity score. They suggest a middle ground metric in which they use hierarchical metrics that are commonly used in the engineering design field.

Cropley's (2015a) Creative Solution Diagnosis Scale (CSDS) (Appendix III) is one of the newest creativity assessment methods in the literature and is easy to understand. It considers previous assessment methods and develops a new one, building on the earlier ones. It suggests a qualitative evaluation that can be turned into a quantitative evaluation. It measures the "kind of creativity" and "amount of creativity" of engineering products. Judges are expected to rate each indicator using a five-point scale (Cropley, 2015a). First, the solution needs to be "relevant and effective". If the final outcome does not solve the problem as it was supposed to it means it is not effective and it does not matter how surprising or original the idea is (Cropley, 2015a). Then there is the "novelty" criteria, which leads to originality. The third criteria "genesis offers new possibilities for the situation for which the novelty was generated" (Cropley, 2015a, p. 68). The fourth criterion "elegance is concerned with aesthetic aspects of the product" (p. 67). The first two criteria are the pre-requisites for functional creativity and the other two add value to the overall measure of creativity (Cropley, 2015a). Sarkar and Chakrabarti (2011, p. 348) support this way of assessment as they argue not only that the novelty of the product must be identified but also that the degree of novelty needs to be described.

2.4.5.2 Self and Peer Assessment

Today's educational context shifted from the decision-making power of the educators to student involvement in the assessment process. Self-assessment means rating one's own performance and peer assessment is rating others' performances (Falchikov, 2003). In higher engineering education, self and peer assessment are regularly used and recommended for helping students "to learn more effectively" (Hanrahan & Isaacs, 2001, p. 53) and helping to develop their evaluation skills (Mitchell, 1998). More importantly, peer assessment gives students the opportunity "to see the work of other students" (Hanrahan & Isaacs, 2001, p. 65).

As Andersen (2001) highlights, the tutorial sessions are good occasions for students to practice oral presentations and to get feedback from their peers. However, Treffinger et al. (2002) warn that using only student assessment as an evaluation tool might be dangerous because the assessment may not give an effective measure of all the aspects that need to be evaluated.

2.4.6 Types of Learning in Engineering Pedagogy

It is believed that people's learning styles are derived from their personality type, educational background or professional career. However, they are not fixed and can show alterations (Beckman & Barry, 2007). "People learn at different rates, and in different ways with different subjects" (Barr & Tagg, 1995, p. 19).

From the learning sciences, Barron (2006) has popularised the idea of a "learning ecology" that can encompass the general array of inputs to a learning experience beyond the classroom. She (2006) states that a big part of the learning happens out of school for adolescent students and they have a lot of learning opportunities. After conducting an empirical study, Barron (2006) declares that "interest" is the first trigger for learning, then once interest is developed, individuals employ a variety of strategies for further learning. Finally, she argues that interest-driven learning is "boundary crossing and self-sustaining' (2006, p. 218).

Felder (1996) summarizes some models of learning styles that were effectively used in engineering education (Appendix IV). Froyd et al. (2012) emphasize the efficiency of "cooperative, problem-based, and inquiry-based" student learning when compared to presentation based lectures. In engineering education focusing on student learning is essential. Hubka and Eder (2003) support learning by both theory and practice in design education.

This next section reviews three types of learning that are present in engineering design units:

- Studio type learning
- Collaborative learning
- Problem/Project Based learning

2.4.6.1 Studio Type Learning

Previous research explains that alternative methods to traditional classroom-based lectures enable more learning (Barr & Tagg, 1995). The National Science Foundation (NSF) reports that "a new physical environment" should be one of the changes in engineering education, which allows active, collaborative, modular, hands-on and integrative learning (Meyers & Ernst, 1995).

The design studio is a traditional type of education tool, used mostly in architecture and design schools, in which students complete a design project under supervision (Denton, 1998). Students learn how to design by "doing rather than by studying or analysing" (Lawson, 2006, p. 7). The major advantage of a design studio environment is having a "one-on-one desk critique" session where the student can discuss their progress with the instructor regularly and frequently (Goldschmidt et al., 2010). Goldschmidt et al. (2014) see design critiques as the "bread and butter" of studio activity, which are described as a discussion environment between the student(s) and the instructor. Apart from this a formal review at the end of the assignment is carried out by a jury. Students present their finished projects, which are consequently discussed and assessed by a jury, consisting of invited professionals (Goldschmidt et al., 2014).

The use of the studio environment for learning started with the Ecole des Beaux Arts in the early 19th century, which later on influenced the North American education system (Goldschmidt et al., 2010). Then, the Bauhaus was formed in 1919 in Germany and survived until the 1930s, but the influence of this school affected the whole world (Goldschmidt et al., 2010). Afterwards, most design schools adopted this approach (Oxman, 1999).

Lackney (1999) outlines the positive effect of smaller classes for teachers; knowing their students well and revising the curriculum according to student needs and interests. Straight lecturing is relatively ineffective when compared to interactive learning techniques used in studio-based subjects. The success of studio learning led some educationalists to think about how to apply all learning in this way (Lackney, 1999). Although, learning through the studio might be a good experience it does not necessarily end up with higher marks (Lawson, 2006). Traditional lecture based teaching has been criticised for being passive, and being exam focused; nevertheless, there are many evidence based research reports showing that the traditional approach is preferred in Australian universities (Nepal, 2013).

2.4.6.2 Collaborative Learning / Team working

A large and growing body of the literature has investigated the positive effects of collaborative learning and benefits of team work in engineering design education (R. A. Howard, Carver, & Lane, 1996; Felder et al., 2000; Pierrakos et al., 2008; Dutson et al., 1997).

Group-based collaborative learning is a better option than individual learning for problem-solving tasks as it allows multidisciplinary interaction (Kettunen, 2011). However, R. A. Howard et al. (1996), depending on the previous literature, argue that cooperative learning is not just forming groups and assigning them a problem to solve. Group members should set their goals and show progress all together. Students need to learn leadership, communication and time management skills. It is also expected that the teams do self-evaluation during the problem-solving process (R. A. Howard et al., 1996; Felder et al., 2000).

There are some difficulties with team working. Timing is easy when you are alone but finding an available time that suits everyone in the team might be harder (Cross, 2011), especially in an educational context if students have other working responsibilities. Framing the problems is another issue within a team. Individuals can form their own framing but a team has to come up with a common understanding of the problem. Another disadvantage of teamwork is the conflict that might arise between team members (Cross, 2011). Although team working is often perceived as a positive technique in a design process the benefits of this are not achieved if the workload is not properly shared by all the members of the team (Woods et al., 2000). Hence careful consideration is necessary when grouping the teams.

2.4.6.3 Project / Problem Based Learning

A vast majority of literature has been published on creativity in engineering education with suggestions about teaching creative thinking skills during the problem-solving processes (de Bono, 1993; Adams & Turner, 2008; Thompson & Lordan, 1999; de Vere, 2013; Zhou, 2012b). Although some researchers distinguish Problem Based Learning (PBL) from Project Based Learning (PBL), they amount to the same thing as they are both "student-centred approaches to learning" (Zhou, 2012c, p. 109). Accordingly, in this research PBL is accepted as both project and problem based learning.

PBL is widely known for presenting open-ended problems within a team based collaborative learning environment. It is a powerful student centred pedagogy that allows students to learn essential skills (Pierrakos et al., 2008). During PBL students work on "complex problem that does not have a single correct answer" (Hmelo-Silver, 2004, p. 235). Students can experience self-directed learning and reflect on what they have learned (Zhou, 2012c). "PBL generates a more stimulating and challenging educational environment" (Wood, 2003, p. 330). In the traditional lecture approach to teaching the problem is given after each lecture for students to practise applying the knowledge they learned in the lecture. However, in PBL the problem is given even before learning how to solve it. This encourages students to search themselves for the knowledge they need to solve the problem (Woods et al., 2000). Reflection is another critical activity during the problem-solving process (Schon, 1993; Adams & Turner, 2008).

PBL has been used in many areas of higher education (Treffinger, 1995). Aalborg University in Denmark was the first higher education institution founded on project-based learning pedagogical perspective (Dym et al., 2005). Although it has been used across engineering disciplines it still has not been integrated in the whole curricula; it is addressed usually at the upper level subjects in final year projects (Pierrakos et al., 2008). Much of the current literature asserts that the use of PBL has advantages in engineering design education (Khalaf et al., 2013). PBL has been used as the primary teaching and learning strategy in most design schools and PBL exercises can be used to develop creativity (Christiaans & Venselaar, 2005; Felder, 1987). Engineers Australia (2014) prefers a problem-based teaching and learning approach at both undergraduate and postgraduate engineering levels. Due to some issues, such as resource limitations, teaching staff's difficulties or student expectations and beliefs, PBL has not been realised effectively in Australian universities (Cross, 2008).

Problem-solving skills are essential and important for engineers (Treffinger et al., 2002; Nordstrom & Korpelainen, 2011). Engineering always involves problem-solving (Cropley, 2015a; Mitchell, 1998) and creativity is a part of problem-solving (Cross, 2008; de Bono, 1993). However, "not all creativity involves problem-solving, and not all problem-solving requires creativity" (Runco, 2004, p. 680).

The teaching of creativity would be difficult if it was not integrated in problem-solving exercises (Santamarina, 2003). PBL is "a strategy of developing creativity" (Zhou, 2012c, p. 99). Engineering students develop their creativity skills through practising problem-solving (Liu & Schonwetter, 2004; Cropley & Cropley, 2000). Therefore, creativity training must be considered as a long-term project for integrating into the PBL curriculum (Zhou, 2012b).

2.4.7 Conclusion

Although engineers need technical skills, creativity is also central to engineering. Creativity can be learned and taught and it is mostly required in the problem-solving process. Education has a big role to play in relation to teaching creativity and creative thinking. However, integrating creativity into engineering curriculum is still an issue to some engineering design programs. There are significant points for fostering creativity in an engineering context to overcome the barriers, such as providing motivation for students, using a studio environment, sketching and drawing, using creativity tools, team working and establishing positive student-instructor relationships.

From professional associations to educational institutions and researchers all suggest redesigning the undergraduate engineering education to involve creativity as a core part of the curriculum. However, there is a debate about when and how to best embed creativity skills in the curriculum. Some researchers focus on the first year of engineering education, whereas others highlight the final year to better prepare graduates for the industry.

The role of design and design thinking in the engineering curriculum has been emphasised numerously and it is suggested that engineering should see design pedagogy as a model for enhancing creativity. Therefore, a change is required in STEM education by seeing the design education as a potential. However, the most effective way to change the culture in an educational context is to first change the beliefs of the individuals involved in education.

Everything changes very fast in the century that we live in. Even new technologies can quickly become obsolete. With this changing technology, people's life practices and therefore their needs change as well. This evolving process requires constantly new, innovative and intelligent solutions to complex problems in the world. Which is when the engineers step in. They need to be good problem solvers and this approach starts with their education. If we do our best to make our engineering students to be the creative thinkers of the future, they will continually bring innovative solutions to our existing and future problems.

3 CHAPTER THREE: METHODOLOGY

3.1 INTRODUCTION

The purpose of the study in this chapter is to first examine the creativity issues in ME design education, then to identify aspects in PDE design education that relate to enhancing creativity and promoting innovation that could be applied to ME education. In order to achieve these research aims the study was conducted in two stages:

- Exploration of the current situation of creativity in ME and PDE
- Action Research in ME design units

This chapter introduces the theoretical perspective and the epistemological approach of the study. It begins with explaining the research methodology used for the two stages of the study: Soft System Methodology and Action Research, followed by a description of how these processes affected the cohort of data collection methods and overall analysis. The overall approach of the study is described after a brief explanation of the context of the study. Then the data collection phases are explained in detail. Prior to commencing the study ethical clearance was sought from the Swinburne University Human Research Ethics Committee (Project No 2014/200 and 2014/255).

In this chapter, the first person pronoun "I" is used as the nature of the study is interpretive and constructed by the author.

3.2 THEORETICAL PERSPECTIVE

First of all, I would like to describe my epistemological perspective to the reader because it influences the choice of my methodology and the methods I used. Then I will describe the methodology and finally the selection of the methods within the chosen methodology and epistemology that will produce the best data to answer my research questions.

The main research questions in this study are:

- How to enhance creativity and creative thinking in student engineering?
- How to teach creativity and creative thinking in engineering education in an effective and efficient way?

There are also sub questions, which help to answer the main research question:

- What are the challenges related to embedding creativity in engineering curricula through engineering design subjects and what needs to be done to remedy these deficiencies?

- What are the most effective approaches for teaching creativity in engineering curricula?

- What aspects of teaching creativity are used in Product Design Engineering education programs that could be transferred to the more traditional fields of Mechanical Engineering?

Three fundamental research aspects provide the research framework for planning, implementing and evaluating the qualitative research: "Epistemology, methodology and method" (Carter & Little, 2007, p. 1316). Even though they are defined in various ways in the literature, this study accepts the epistemology as "the justification of knowledge" and methodology as the "justification of the methods of a research project" (Carter & Little, 2007, p. 1317) as shown in Figure 3.1. "Methodology justifies method, which produces data and analysis. Knowledge is created from data and analysis. Epistemology modifies methodology and justifies the knowledge produced" (Carter & Little, 2007, p. 1317) and it guides methodological choices.

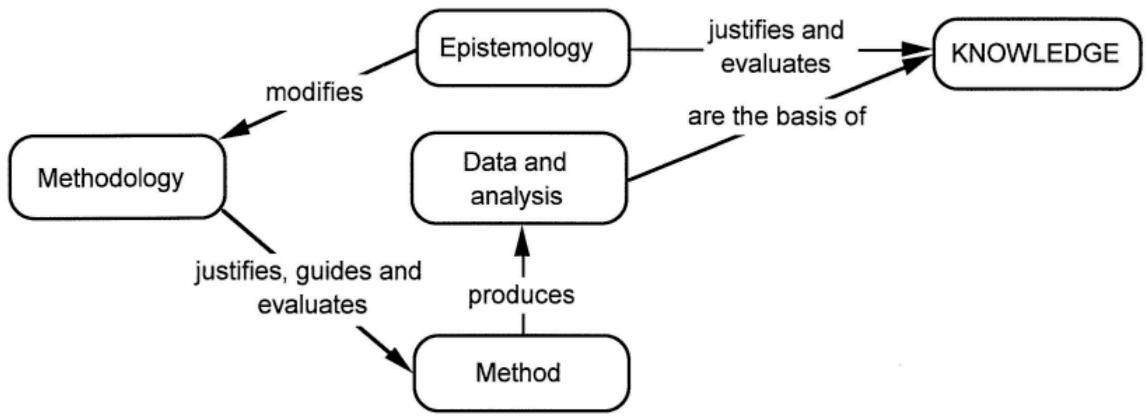

Figure 3.1 The Relationship Between Epistemology, Methodology, and Method (Carter & Little, 2007, p. 1317)

3.2.1 Epistemological and Ontological Approach

This study has a constructive epistemology based heavily on an interpretive approach but also takes support from a positivist approach.

The research investigates a complex organisational culture, including different groups of people. Lee (1991) explains that the common view of doing research in organisational culture, the positivist approach, uses the scientific view known as "logical positivism" and argues that the natural science methods are the only truly scientific ones. There is a belief that researchers must try harder to fit their research into a natural science framework. Otherwise it will not be truly scientific without "formal logic" providing a way of relating propositions to each other and deducing new ones (Lee, 1991). The positivist approach "assumes that a single true reality already exists out there in the world and is waiting to be discovered" (Tracey, 2013, p. 39). Whereas the interpretive approach argues that the study of the institutions and the people involved in them is foreign to natural science and that only using natural science will not be enough to capture social reality in organisational research. The interpretive approach sees the methods of natural science as insufficient for studying social reality. That is why these two approaches appear to be in opposition (Lee, 1991). "From an interpretive point of view reality is not something out there, which a researcher can clearly explain, describe, or translate into a research report" (Tracey, 2013, p. 40). Considering these different approaches, Lee (1991) proposes a feasible framework to integrate positivist and interpretive approaches, often believed to be opposed to each other. Lee (1991) believes that they have a common ground and can collaborate. He describes three levels of understanding an organisational culture:

1. "the subjective understanding"
2. "the interpretive understanding"
3. "the positivist understanding"

The first level is the subjective understanding. The second level is the interpretation of the first level. At this stage the researcher constructs and explains the empirical reality. The third level is the positivist understanding. This level obeys the rules of formal logic that apply to scientific explanations in general (Lee, 1991).

“The subjective understanding provides the basis to the interpretive understanding, which provides the basis to the positivist understanding, from which follow predictions about the human subjects’ actions” (Lee, 1991, p. 354). If the positivist understanding is considered without the support of the subjective and interpretive meanings this would result in methodological error (Lee, 1991). It must be kept in mind that whatever has been studied can have different meanings for different participants or the observing social scientist. So the researcher must interpret this reality and try to understand what it means. The researcher must collect “subjective meanings of human behaviours” as well as the objective “publicly observable aspects of human behaviour” (Lee, 1991, p. 347).

What is dealt with in this study is humans. It is not easy to study humans as objects and to find objective laws that work the same under a variety of conditions or situations. Therefore, I used more a descriptive and interpretive approach. In addition to that I got support from the positivist approach for a logical explanation of the findings and results.

The social constructivist view is based on the idea that “we construct our knowledge of our world from our perceptions and experiences, which are themselves mediated through our previous knowledge” (Simon, 1995, p. 115). While I was constructing my own truth, I was aware that there was a subjective world but I could not isolate myself from the objective truth that was obtained from the previous literature. From the objectivist perspective truth is out there and it is explored, whereas from the subjectivist perspective truth is discovered. However, in a constructivist approach I considered both. During this research I look at the phenomenon from a social constructivist perspective. The knowledge gained in this research is the knowledge that I constructed by building relations with the participants -in this case the instructors and the students-.

I engaged in Action Research by reflecting on my practice at Swinburne University of Technology, working collaboratively with instructors in ME and PDE. I was directly involved in this social world as a participant observer.

Even though the knowledge is constructed by me by using an interpretive approach, I present it in a way that can be tested by other researchers in their own educational context. I explained the context that I studied in full detail. However, the readers should keep in mind that the knowledge achieved here is also dependent on time and my -the author- background which shapes my perception. Therefore, I could have perceived some issues as being more important than others.

As Checkland (2000) explained, human beings experience some "situations, issues and problems", but they are not separate from human experience. "They are themselves generated by human beings and no two people will see them in exactly the same way" (Checkland, 2000, p. 33).

During the study, I did not position myself separately from the participants and I tried not to break apart from them. Instead, I got to know my subjects, the participants, and built bridges with them socially as a foundation for getting information from them. I established strong relations with the participants and tried to see the issues from their perspective as well as from my perspective. That is why I had weekly 5 minute discussions and interviews with participants in order to understand the situation better in addition to all the observations I made. I tried to learn the culture by trying to be one of them. I empathised, I tried to see things from other peoples' perspective so that they opened themselves to me more and I could access their personal opinions rather than base information just on my observations. In the end I combined observations from the literature review and my interpretations from the data I collected to prove the truth of my findings.

3.2.2 Soft System Methodology

"Soft Systems Methodology (SSM) is a systems approach that is used for analysis and problem solving in such complex and messy situations (Maqsood et al., 2001, p. 1). It is used to understand the meaning of people's experiences in complex organisational situations (Checkland, 2000; Maqsood et al., 2001; Molineux & Haslett, 2003).

Schein (1984) describes how people learn, pass on and change culture. He suggests if we really want to decipher an organisation's culture we need "to dig below the surface" beyond what is visible and discover the underlying assumptions that are the core of an organisation's culture. Even if we live in a particular culture, it does not mean that we know how it came into being, how it came to its current situation or how it could be changed (Schein, 1984).

"Organizational culture is the pattern of basic assumptions that a given group has invented, discovered, or developed in learning to cope with its problems of external adaptation, and that have worked well enough to be considered valid" (Schein, 1984, p.3). Analysing organisational culture, as can be seen in Schein's diagram (Figure 3.2), starts with the visible artefacts, which are "the constructed environment of the organisation, its architecture, technology, office layout, manner of dress, visible or audible patterns, and public documents". We can describe 'what' and 'how' everything is, however, we cannot understand the underlying logic – "why a group behaves the way it does" (Schein, 1984, p. 4). For analysing members' behaviours, we look for the values that govern behaviour. It is not easy to observe the values directly, therefore we need to find the key members of the organisation and carry out in depth interviews (Schein, 1984). Values transform into "an underlying assumption" about how things really are. Values are explicit and questionable, whereas assumptions are unquestionable and taken for granted (Schein, 1984, p. 4).

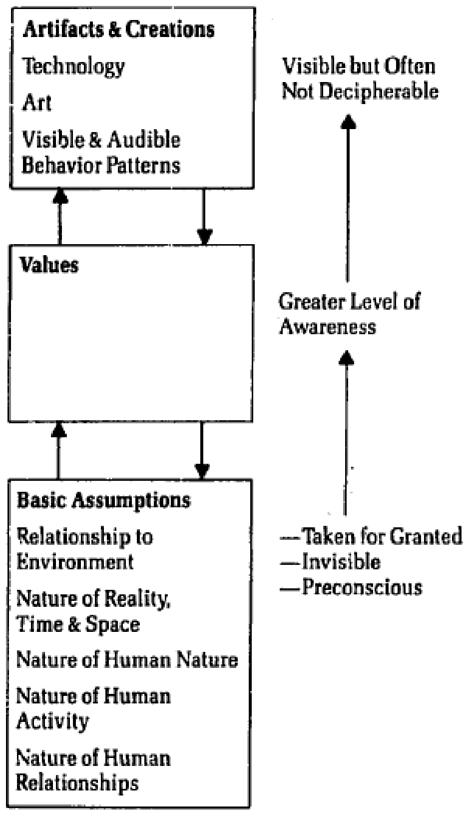

Figure 3.2 The Levels of Culture and Their Interaction (Schein, 1984, p. 4)

While investigating organisational culture, Schein (1984) suggests analysing the process and content of socialisation by interviewing the older peers of the members.

Additionally, he suggests analysing the organisation's history by collecting data from documents, interviews and surveys of present and past key members. For every incident it is important to determine "what was done, why it was done and what the outcome was". A joint inquiry needs to be done with the insiders who are the representatives of the culture to reveal the basic underlying assumptions (Schein, 1984).

Considering Schein's (1984) suggestions about studying organisational culture I tried to do my interviews with the old and new members of the engineering faculty. I asked many questions of engineering instructors about their educational background to better understand the engineering culture and its history in order to understand the current situation, and to be in a position to make suggestions for the future. Many questions were asked to instructors shown within the Appendix V and following are the top three most critical questions for this area of study:

- What do you understand about applying creativity in the context of an engineering project?

- Can you compare way the units were taught in the engineering education you had with the way the units are delivered in the current engineering education course?

- How were you encouraged or directed to generate innovative ideas to deal with an engineering problem during the design process when you were studying engineering?

To change the culture of a group the people in that group need to change through changing the "modes of activities", changing "languages" and changing "social relationships" among the group members. Change in any one will eventually effect the others (Kemmis & McTaggart, 1988). This change could be made possible through Action Research that sees people as social beings who are actively participating in life and relating to each other. Therefore, all the interventions suggested or done during the Action Research in this study consider the situation as a whole rather than being individual experimental case studies. "Improving education is not just a matter of individual action. It is also a matter of cultural action" (Kemmis & McTaggart, 1988, p. 34).

Methodology forms the research questions and study design and it explains the choice of methods (Carter & Little, 2007). In organisational research, like this study, the interpretive approach is preferred to the more traditional positivist approach (Lee, 1991). That is why Soft System Methodology (SSM) is found to be the most suitable research methodology to use in this study as it helps to investigate the phenomenon of creativity in context. The literature also shows that SSM is ideal to study unstructured real-world situations like this case (Checkland, 2000; Maqsood et al., 2001; Williams, 2005) and it seems a sensible choice "to lead to insights" (Checkland, 2000, p. 29). SSM is a "sense making approach", allowing "exploration of how people in a specific situation create for themselves the meaning of their world" (Checkland, 2000, p. 12). It is suitable for diagnosing and addressing complex organisational systems and it tries to evaluate plural views and values (Maqsood et al., 2001; Molineux & Haslett, 2003). Even though studying human affairs is subjective, SSM brings rigour into the thinking about the process (Checkland, 2000). The SSM approach aims to analyse the complexity from different people's perceptions rather than to over simplify this complexity (Andrews, 2000). Torlak (2001) suggests to using SSM "when 'interactions' in the system are cultural and the 'situations' are dominated by the viewpoints of the observers" (p. 14), which makes SSM a suitable methodology to use in my research.

SSM is an ideal methodology when:

- "Rigor and deep insights are needed" if there are "multiple goals" (Williams, 2005):

I tried to help students to be more creative, to help instructors to motivate the students to be more creative and to make alterations in the unit structure for enhancing creativity during the design process.

- There are "different views, perspectives and assumptions" (Williams, 2005):

I –the researcher-, instructors, the unit conveners and the students have various perspectives and assumptions.

- The whole situation is "very entangled" (Williams, 2005, p. 19):

The situation is entangled, because I tried to see the phenomenon from the students' perspectives, from the instructors' perspectives, from the unit conveners' perspectives and also differently from the engineering and design perspectives. Therefore, SSM is used to identify and clarify the problems and to develop convenient models for interventions for the Action Research to be conducted.

Williams (2005) summarizes Checkland's "seven stages" of SSM as shown in Appendix VI. I used this seven step model, which allowed me to explain the steps in detail. They will be addressed step by step in Chapter Four and Five. This section just gives an overview of the methodology used.

3.2.3 Action Research

Kurt Lewin is the pioneer of Action Research method, which he developed in 1940s, believing that studying real social events is not possible in a laboratory. Action Research gives flexibility to the researcher by being "adaptive, tentative and evolutionary" (Burns, 1997, p. 355). It is also "situational, collaborative and participatory" (Burns, 1997). "Action Research brings together the acting (or the doing) and the researching (or the inquiry)" (Punch, 2009, p. 135). It is the type of research believed to be suitable for this study, because first of all Action Research is a convenient method to use in educational issues and it is used in educational settings to improve and increase student achievement (Ferrance, 2000), which is the aim of this research from a creativity perspective. Action Research is "diagnosing a problem in a problem specific context and attempting to solve it in that context" (Burns, 1997, p. 347). Amabile (1998) claims that if people want to get full benefit from creativity they need to allow time, because change needs time. Therefore, instead of instantaneous evaluations, a long-term evaluation process is preferred through Action Research.

There has been an increased number of Action Research studies in educational research publications (Zeichner, 2001). Kemmis and McTaggart (1988) declare that in Australia, Action Research is highly preferred in educational contexts in the area of curriculum review and development. Kemmis et al. (2014) continued their research over the years in Australia in the educational field. Action researchers are more interested in the improvement of knowledge about teaching, learning and the curriculum (Kemmis & McTaggart, 1988), rather than simply adding to the body of educational knowledge in articles and books (Burns, 1997). Action Research generally takes place in a school setting in the form of collaborative activity among staff who are looking for solutions to daily problems. The aim of it is to search ways of improving student achievement. It is an improvement approach by learning from the results of finding solutions to problems. (Ferrance, 2000). Action Research allows participants to question their own educational performances in a systematic and careful way (Ferrance, 2000). Therefore, it is the preferred method for this study, with its aim of enhancing creativity in engineering education context by also learning from the results of the actions.

Action Research uses "systems thinking" in cycles of learning and reflections to understand the variety of perceptions by people who are involved in any situation (Maqsood et al., 2001). During the Action Research process there is a systematic learning process that is open to surprises and new opportunities. Action Research is different from other research methods by having a repetitive and cyclical nature (Punch, 2009). It "develops through the self-reflective spiral: cycles of planning, acting, observing, reflecting" (Kemmis & McTaggart, 1988, p. 22) in sequence. It starts with small cycles, by defining the issues and assumptions in a clearer way (Kemmis & McTaggart, 1988). Cherry (1999, p. 8) summarizes this process as "continuing and iterative cycles of planning, action and review". During this process action is continually fed by reflection and planning new ideas (Cherry, 1999), the stages might overlap and the initial plans may be modified with new experiences (Kemmis et al., 2014). Then the whole cycle repeats itself with new, updated plans. Figure 3.3 shows the cycle of the Action Research method.

Figure 3.3 Action Research Diagram (Cherry, 1999)

The cycle of Action Research that is recommended by many researchers (Cherry, 1999; Ferrance, 2000; Kemmis & McTaggart, 1988; Kemmis et al., 2014) is summarized as follows:

1.Planning

It is the process of “developing a strategy for collecting data, solving a problem or implementing an idea” (Cherry, 1999, p. 10). Kemmis & McTaggart (1988) briefly summarizes this phase: The process starts with a general idea where there is a need for improvement. Researchers identify an area and decide what needs to change and where they believe it is possible to have an impact. After identifying the field and carrying out preliminary research the research group then decide on a general action plan. Then it is time to break the plan into achievable segments. The general plan needs to be flexible so it can adapt to unpredictable circumstances and previously unrecognised situations.

2. Acting

The next step is to act. It is the phase of “implementing the action, solving the problem, testing the ideas and collecting data” (Cherry, 1999, p. 10).

3. Observing

In Action Research, observation was undertaken to grasp a broader understanding of the situation. Further data was collected through qualitative open-ended interviews (Burns, 1997). Kemmis et al. (2014) argue that keeping a journal is important during Action Research to have reliable documentation of what happened. Description of events, comments, interpretive notes and reflections are all recorded in the journal. This process provides an atmosphere of observing the effects of the action implemented in order to reflect on the next steps for further improvement (Ferrance, 2000).

4. Reflecting

The final stage is interpreting the data and evaluating the overall project (Burns, 1997). It is “to analyse, synthesise, interpret, explain and draw conclusions” (Kemmis et al. 2014, p. 108). In this phase, a problem or an issue is identified and defined. An idea, hypothesis or vision is developed and other possible interventions are considered. It involves systematically reflecting on the experience by asking many questions about the action being done, its impacts, peoples’ reactions, the consequences of the act and what can be done differently (Cherry, 1999). It is “studying the consequences of action, making sense of the experience, describing the process, developing a theory and knowledge”, and more importantly deciding what to do next (Cherry, 1999, p. 10). Kemmis et al. (2014) define the reflective phase as the time of modifying the action plan and deciding if a new direction needs to be chosen. The actions are reviewed and, if necessary, alternative appropriate actions are prepared.

3.3 CONTEXT OF THE STUDY

As noted by de Vere (2009, p. 5) “engineering must look to design pedagogy as a model for the fostering of creativity and innovation through a structured program of design integrated throughout the curriculum”. This explains why PDE education has been accepted as a benchmark for design pedagogy within this research framework, since it is an engineering discipline with a design element in it – making it perfect as a model for the context of this study. A design discipline, in this case Industrial Design, which is the closest design discipline to ME, could have been chosen to study. However, Swinburne University of Technology has PDE, which is actually not only closer to ME, but also provides “an appropriate ‘engineering’ (rather than design) response” (de Vere, 2013, p. 358).

This study took place in Swinburne University of Technology in Melbourne, Australia. It was conducted between the years of 2014 and 2017. The studied courses are Mechanical Engineering and Product Design Engineering, both four-year courses in the Faculty of Science, Engineering and Technology. Swinburne University of Technology defines them as follows:

ME is “the design of technology involving physical motion”. This course provides students “with analytical and scientific expertise and management skills to design mechanical systems and manage teams in a broad range of applications”. PDE is “project-driven, combining the disciplines of creative design and innovation with studies in engineering science, sustainable material selection and manufacturing processes”. Students will gain “the skills to design and develop high quality products for the Australian and international markets, or use the course as a pathway into research or further learning” (Swinburne University of Technology, 2015).

ME at Swinburne University of Technology offers only two engineering design units: Machine Design (MD) and Mechanical Systems Design (MSD). They both have a lecture and tutorials format. However, PDE offers a design studio every semester. All design units are project driven.

3.4 OVERALL APPROACH OF THE STUDY

As "creativity is the essence of engineering" (Santamarina, 2003, p. 91), it is believed that creativity is necessary and valuable in engineering education. Under the light of the previous research, suggesting that creativity must be promoted in engineering education, this study explores ways of embedding creativity and creative thinking in engineering education. It is trying to accomplish this by doing Action Research in ME design units by leveraging the creativity education in PDE. The research is conducted in two stages:

Stage 1: Exploration of the current situation of creativity in ME and PDE (Chapter Four)

Stage 2: Action Research in ME design units (Chapter Five)

In order to enhance creativity and creative thinking in ME design units, initially the current situation is described in ME and PDE in Stage 1 (Chapter Four). Comparing these two disciplines was an assumption backed up by the literature that creativity was more encouraged in PDE, so other engineering disciplines could take benefit from it. Some exemplary approaches in PDE that could be used in ME were defined. Then, in Stage 2 (Chapter Five), Action Research was conducted in two consequent semesters in two different design units in ME. Even though there were two cases of Action Research, I saw these phases as a whole, as both studied units are the consecutive design units in ME.

Investigating creativity in an educational context by trying to see the phenomenon from every party's perspective is not a simple task but a complex one. Therefore, a Soft System Methodology is chosen in order to investigate the phenomenon. What I accept in this study is that creativity is an essential skill for engineers and is not special to some unique talented people; it can be taught and learned. Engineering students need creative thinking skills in order to be successful in their profession, to solve open ended engineering design problems and to come up with innovative solutions. While conducting this research I accepted that reality occurs in relation to humans. Therefore, I valued the participants' perspectives and their experiences in this study.

3.4.1 Qualitative Approach

This study has a qualitative approach. A qualitative researcher looks at things holistically and comprehensively (Punch, 2009). If individuals are to be studied in their daily life qualitative methods are the best way to do it (Burns, 1997). It "is especially well suited for accessing tacit, taken-for-granted, intuitive understandings of a culture" (Tracy, 2013, p. 5). Qualitative research is particularly interested in the way in which the world is "understood, experimented, or produced" (Mason, 1996, p. 4) by people's lives, behaviour, and interactions (Strauss & Corbin, 1990). It is also interested in the "meanings" of social interactions (Silverman, 2000). Qualitative research is interpretive, (Mason, 1996); it rejects "the natural sciences as a model" (Silverman, 2000, p. 8). It produces valid causal descriptions by analysing the influence of particular events on others, and understanding cause-effect relationships within a context (Maxwell, 2004). It "helps people to understand the world, their society, and its institutions" (Tracy, 2013, p. 5). These make qualitative research perfectly aligns with my epistemological perspective.

Carter and Little (2007) argue that qualitative research deals with more text data rather than dealing with numerical data (Carter & Little, 2007). Qualitative data uses words, unlike numbers as used in quantitative data. This study did not use multiple observers; the only observer was the author herself. However, I played a role in making the participants observe themselves and analyse their behaviour by doing in depth interviews with them. Data has been collected and analysed concurrently throughout the process; it is not collected first and then analysed later. No quantitative coding methods are used as the collected data was not quantitative but qualitative in quality.

3.4.2 Approaches to Validity and Reliability

In qualitative research, the best way to understand what is reliable and valid is "triangulation", meaning "the use of two or more methods of data collection in the study of some aspect of human behaviour" (Burns 1997, p. 324). "Triangulation contributes to verification and validation of qualitative" analysis by achieving findings through different data collection methods and different data sources (Burns 1997, p. 325), such as using various research settings at different times, collecting data by various methods, or working with different participants. This gives validity to the process and maximizes the generalisability of the research (Cherry, 1999). Therefore, this study uses triangulation in the data collection and triangulation between the data sources to assure the validity and reliability. Checkland (2000) argues that qualitative research can never be generalised; only transferred to similar contexts. For the qualitative researcher, "the truth of human behaviour is not independent of context, it is not context-free" (Punch, 2009, p. 161).

Triangulation uses "similarities and differences in the data from different sources" to increase the rigor of the research's progress (Cherry, 1999, p. 58). Each data source is expected to stand in each point of the triangle. The teacher has a good position in providing information about his/her intentions and objectives. The students are in the position to explain how the teachers' actions affect their ways of learning. On the other hand, the participant observer collects data about all the observable features of the teacher-student interaction (Burns, 1997; Punch, 2009). Therefore, data sources in this study were the students who are taking the units, the PDE and ME unit conveners, unit instructors and me, the author. The main research methods used after doing the literature review are observations, surveys and interviews. The information is collected in various settings throughout three educational semesters, not just at a particular place in a limited time. In the end, I brought all the data together and established a substantive total. While doing this, the context of the study is explained in detail, which also gives us validity.

Reliability in this qualitative study depends on the constancy of the situations. Therefore, two phases of Action Research were conducted to see if the situations were constant. Not every fragment of the collected information is considered here. What is considered is the essence of the results accessed through various methods. If the same result presented consistently under the same or similar conditions, then this indicated reliability. Additional methods, such as secondary interviews with the participants or reviewing online student surveys and feedbacks, were used to get a better understanding, "In Action Research, theories are not validated independently to be applied to practice; they are validated through practice" (Burns, 1997, p. 346). Action Research has an internal validity which means the findings are relevant for a unique setting in a special context (Burns, 1997). Much of the information generated from Action Research can be transferred to a similar context having similar characteristics (Anderson, 2005). Therefore, all the steps taken, the place, the time, the cohort of participants were described in detail. The similarities and differences between the situations need to be analysed to make it clear if it is possible to use the findings of this study in other situations.

3.4.3 Weaknesses and Limitations of Qualitative Research

This study has an interpretive approach and I am aware of the subjective nature of the interpretations. I tried to be objective by looking from a researcher's perspective. However, I am acknowledging the fact that my educator identity as a designer might have affected my interpretations. Also in Action Research, the researcher is a researcher-participant and his/her practice or interventions in the context of Action Research is an integral part of the research project. I used various methods to access data and considered the commonalities in the collected data. It is not possible for me to access all the attitudes, motivations or beliefs of participants as fixed measurable units. However, it is one of the main aims of the research output to make it as generalizable as possible and in this case it can be done by describing the context in full detail. Tracey (2013) claims that in qualitative approaches everything is described from the researcher's point of view and it is context specific. So it should be kept in mind that some result findings and recommendations "can only have relevance for that unique setting" (Burns, 1997, p. 353).

What I will present in the end will be a product of interactions between me and the participants in a specific context. The knowledge that I constructed in relationship with the participants in this specific place and time might show differences or commonalities from another time and place. Therefore, the context of this study is explained in detail for further studies.

I have been an active contributor throughout this research. My job was to engage with the participants to create and understand the phenomenon together. As Carter & Little (2007, p. 1321) indicated "epistemology influences the relationship between the researcher and the participant". I formed a caring relationship with them and I also allowed the unexpected to happen. I could not get into participants' heads; all that I could do was to observe the way people interacted with me and among each other. One of the most important points to be clear about is that the participants of this study were not passive; they had agency in the research process and they became the co-creators of the study. I assumed the participants spoke the truth and I built my study on it. However, it is not possible to be absolutely sure that people are always honest. Thus, I relied on not fewer but many participants' reflections.

I always stayed in close relationship with the instructors. In order to thoroughly understand the students' points of view, I needed to set aside my own assumptions. The reader also should keep in mind that however hard I tried to be a part of the culture, due to age difference and my status in the organisation –as a PhD researcher and a lecturer- I established closer relationships with the instructors rather than the students. I became colleagues of the instructors, rather than becoming the "mates" (friends) of the students. I participated in instructor meetings rather than student study groups. I become a complete participant, described by Tracy (2013, p. 107) that allows "insight into motivations, insider meanings, and implicit assumptions". When you become a complete participant, other participants feel that they are dealing with a friend or a colleague rather than a researcher, which encourages "candour and openness" (Tracy, 2013, p. 107). Different or additional results might be found by another researcher who is more involved with the students.

3.4.4 Permission and Approval for data Collection Phase

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the National Statement on Ethical Conduct in Human Research. Ethics approvals were taken in steps:

1. SHR Project 2014/200 (Appendix VII) was approved for the period from 04/08/2014 to 01/03/2018. It was for observation in Mechanical Systems Design unit in 2014 educational year.

2. SHR Project 2014/255 (Appendix VIII) was approved for the period from 06/11/2014 to 30/04/2018. It was for observation in Product Design Engineering units and doing interviews with PDE students and instructors. Additionally, it was for doing Action Research via observing, administering surveys and doing interviews with the students and instructors, participating in instructors' meetings in Mechanical Systems Design and Machine Design units in 2014 and 2015 educational years.

3.4.5 Ethical Issues

Throughout the whole process, I was the only researcher who was in contact with the participants of the study. All collected data was and will be kept confidential in accordance with the ethical requirements.

As the observations are argued to have minimal risk to participants, an opt-out consent (Appendix IX) is used. Students were informed that the investigator was going to be observing the class and if any student felt uncomfortable being observed for research purposes, they were able to notify the investigator and nothing was going to be recorded about that student. If a number of students felt uncomfortable the researcher was going to leave the tutorial. However, that did not happen.

There was another consent information statement attached to the survey as the cover page. Before administering the survey, students and tutors read it first. If they agreed, then they did the survey; it means they had given their consent. Before starting the interviews, the participants were expected to read the consent information statement and to sign the consent form. Small modifications were done in the consent forms when being handed to students or instructors; examples of consent statements for surveys and interviews are provided in the Appendix X and XI.

3.5 STAGE 1: EXPLORATION OF THE CURRENT SITUATION OF CREATIVITY IN ME AND PDE

The methodology I chose here shaped the questions that I asked and the study design I implemented. The study uses SSM for this stage of the research, which was described in section 2.2. I simplified Schein's model, which can be seen in Figure 3.2, according to the boundary parameters of this research and created the levels of culture for this study (Figure 3.4).

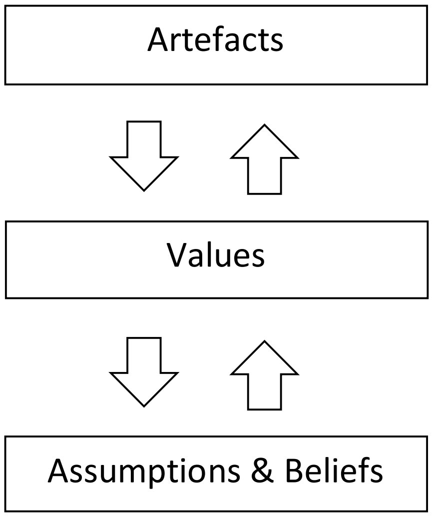

Figure 3.4 The levels of organisational culture for this study

The artefacts and behaviour in this study refer to the things that are already available such as my observations in the studied units, the unit outlines, project briefs, rubrics, class environment, student and instructor relations and their opinions about creativity. I can easily access and measure these. But for understanding the behaviours of students and instructors, I look for the values that control their behaviours. To understand why a group of people behave the way they do, values need to be figured out. Although I cannot measure these values I am interested in interpreting them. There are also underlying assumptions and beliefs that establish the values. I am also interested in these assumptions and beliefs of the participants, which is a further level of analysis. The underlying assumptions, beliefs and accordingly the values of instructors and students towards creativity are the major factors in influencing creativity in engineering. This complex situation can best be described as organisational research. The Figure 3.5 below shows the complexity of the organisational culture that consequently I worked with in two disciplines:

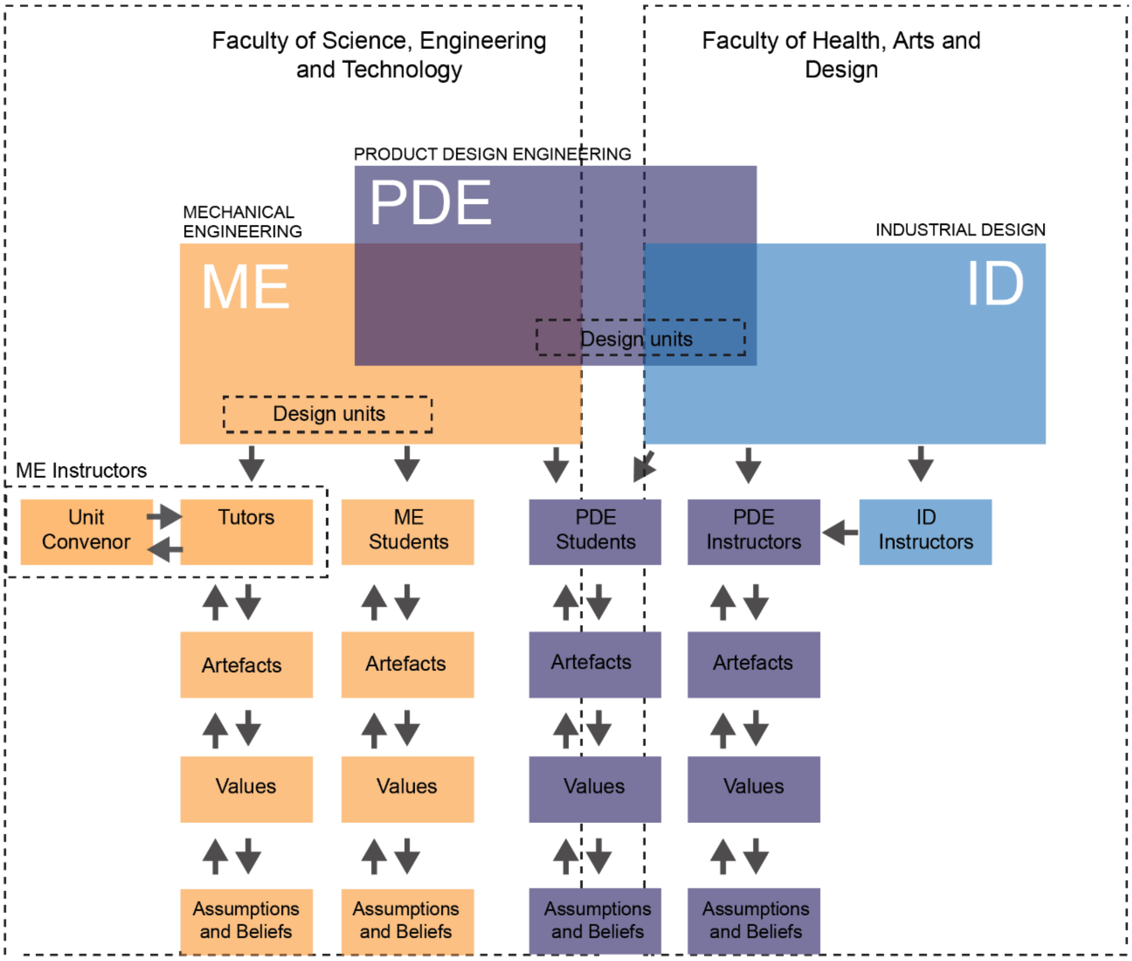

Figure 3.5 The Organisational Structure of the Study

These are the used abbreviations in the study:

Interviews with Students: Discipline - S - Number (ME-S5, PDE-S1 and etc.)

Interviews with Instructors: Discipline - I - Number (ME-I1, PDE-I3 and etc.)

Interviews with Mechanical Engineering Unit Convener: UC

Student Online Survey: Year - Unit - SOS (2015-MD-SOS, 2016-MSD-SOS)

Student Feedback Survey: Year - Unit - SFS (2015-MD-SFS, 2016-MSD-SFS)

Student Written Survey: Year - Unit - SWS (2015-MD-SWS, 2014-MSD-SWS)

E-mails from the UC: (E-mail day/month/year)

Unit Outlines: Unit code – UO – Year (MEE40002-UO-2014, MEE30003-UO-2015)

3.5.1 Data Collection and Comparison Between the Cases

In Data Collection Stage 1 — written in Chapter Four — data is gathered from the following subjects with the aim of addressing the gaps in creativity aspects in ME, examining how PDE approaches the same matter, and discussing the transferable aspects to ME:

- ME – Mechanical Systems Design (MEE40002) lecture and tutorials
  Observations in 2-hour lectures, and in two different 2-hour tutorials
  Interviews with 3 instructors
  Interviews with 2 students
  Surveys with 3 instructors
  Surveys with 21 students
  Learning materials (Unit Outline, project brief, rubric)

- PDE – Product Design Engineering Studio (DPD20002)
  Observation in two different sections of 2.5 hours of studio class (total 5 hours per week)
  Weekly in class discussions with students
  Interviews with 2 instructors
  Learning materials (Unit Outline, project brief, rubrics)

- PDE – Advanced Product Design (DPD30001)
  Observation studio class 2 hours per week
  Interview with 1 instructor
  Interviews with 2 students
  Learning materials (Unit Outline, project brief, rubric)

The PDE units are design studio subjects and are taken by only PDE students. Whereas ME design units are taken by ME, PDE and Robotics and Mechatronics Engineering (only Machine Design) students and they are ME design units. They all have problem-solving in their content, which is supported by many researchers as an appropriate process to foster creativity (de Vere, 2009; de Vere et al., 2010a; Dym et al., 2005; Stouffer et al., 2004; Treffinger et al., 2002).

Mechanical Systems Design (MEE40002 – ME design subject), studied throughout the 2nd semester in 2014, which is taken by 3rd and 4th year students. It involves 2 hours of lecture and 2 hours of tutorial each week for a 12-week period. The gender ratio is typical of engineering units. Total participants are 170, where 130 of them are male. The lectures are done in a large lecture hall open to all 170 students to 1 instructor. The instructor-student ratio in the tutorials is 1 to 13-23 depending on how many students attend each week, with the maximum capacity of 25.

Product Design Engineering Studio (DPD20002 – PDE design subject), is studied throughout the 1st semester in 2015, which is a 2nd year subject. It involves 2.5 hours of studio and 1.5-hour Illustration and Digital Visualisation tutorials each week throughout the 12-week term. The studio consists of 12-13 students to 2 instructors.

Advanced Product Design (DPD30001 – PDE design subject), is studied throughout the 1st semester in 2015, which is a 3rd year subject. It involves 2 hours of studio and 2 hours of tutorial each week throughout the 12-week term. The studio is consisted of 12 students to 2 instructors.

There is only one difference with PDE Studio (DPD20002). The author has worked as a lecturer with two different groups of students in the Product Design Engineering Studio for the last 7-weeks of the 12-week semester. In other cases, she was only the researcher observer.

3.5.2 Research Methods

This study used a mixed method approach, because triangulation helps to neutralise the disadvantages of all types of methods (Burns, 1997). The research methods are explained as follows.

3.5.2.1 Observation

In qualitative approaches, using observation as a method of data collection is generally unstructured allowing one to focus on the larger patterns of behaviour (Punch, 2009). For this phase of the study, semi-structured observation has been the most significant method for collecting data. A semi-structured non-participant observation protocol (Appendix XII) that is prepared according to educational research is used to observe students, instructors and the class environment in a design class. It also allowed for capturing unpredicted observations. The advantage of this method was the reliability, providing first hand insight into what was happening, which I could triangulate with the other collected data.

"Non-participant observation involves merely watching what is happening and recording events on the spot" (Burns, 1997, p. 318). It is also worth noting that the presence of the researcher or the observer might have changed the behaviour of people being observed (Burns, 1997). Indeed, when I was in a class of 10 or 15 students it was not always possible to be a non-participant, particularly if they asked me a question. But, as an observer I tried to minimise my interactions with participants to focus on the stream of events.

The reason why a semi-structured observation is preferred is that it is neither based on "strict predetermined categories", as in a structured observation nor on "the larger patterns of behaviour", as in an unstructured observation (Punch, 2009). I needed a larger picture in view, but about a specific issue: creativity. Hence semi-structured observation is done for the initial part of the study (Chapter Four) in a natural open-ended way. However, observations have limitations, such as mixing the spontaneous occurrences with simultaneously happening events. Therefore, I preferred to be present in the subjects through the whole semester and noted the repetitive occurrences as well as the simultaneous ones.

The observations tried to identify instances of creativity and creative thinking and how, where and in which conditions they occurred. If no creativity instances were observed, observation focused on whether any creativity blockers were present in terms of the student, instructor, environment and their interrelations. Throughout the tutorials, behaviour of the students and instructors, their approach to given exercises, ways of solutions to given problems, classroom motivations and discussions, products, artworks, ideas that came up, and the interaction between the students were all observed and documented. The process was also open to note any unexpected events apart from those questions. Observations were all noted during the observation phase subsequently or right after leaving the field in the form of diaries as suggested by Burns (1997).

These are some of the questions I tried to have answered during the observations, all of which can be found in Appendix XIII:

- How does the students' design process evolve during tutorials? Can we observe the phases of creative design process?

- How does the instructor approach students during the class hours? Do the instructors promote creativity?

- How is the learning environment structured? Are there any issues that might cause blocking of creativity?

Burns (1997) declares that sometimes a study demands to know "what people actually do and say" and compare them with "what they said and did". Qualitative research provides "important insight into interpersonal relationships" (Tracey, 2013, p. 6). The literature (Adams et al., 2003; Treffinger et al., 2002) suggests using different mediums and methods to enhance creativity due to its multidimensional and complex nature. In addition to collected data during observations, survey and interview questions are prepared for further investigation to get a better understanding of the nature of the events.

3.5.2.2 Surveys

The survey method, which is "commonly used in educational research" (Burns, 1997, p. 494) allows for collecting information from a wide group in a very short time. It is also one of the practical ways of getting statistical data as needed. One of the other reasons to use the survey method is the ability to collect information on beliefs, attitudes and motives (Burns, 1997). The advantages of using a survey questionnaire are its cost efficiency and its confidentiality. However, the response rates are usually lower than the interview and not all the questionnaires are returned. Furthermore, It is difficult to follow up on ambiguous and incomplete responses (Burns, 1997).

At the second stage after observations, a survey questionnaire has been administered to students and instructors of Mechanical Systems Design (MSD) The questionnaires (Appendix XIV), which took about 10-15 minutes to complete were distributed to students in two of the tutorials at Week 11, where observations had previously been made. When all the students were handed the questionnaire forms the aim of the study was clarified. Whoever wanted to take the survey was requested to complete the form. The questionnaires were gathered after a given time. Anybody who did not want to fill in a questionnaire was not forced to do it. The questions asked in the questionnaires did not involve any personal information and they were anonymous. Instructors of the tutorials had already agreed to conduct this study in their classes. A different questionnaire (Appendix XV), with similar questions, were provided to the instructors. The instructors were given a few days to complete the questionnaire and they were collected once they were finished.

The steps taken during administering the surveys were as follows (Burns, 1997):

- Planning and deciding the topic to be investigated

- Deciding what the people will be investigated about

- Writing the questions and preparing the layout of the survey

- Pre-testing the instrument to test its efficiency

- Processing the data, coding the collected data and interpreting the results

Different forms of questions are used in the questionnaire, such as closed items, which "allow the respondent to choose from two or more fixed alternatives" (Burns, 1997, p. 467). Even though they achieve greater uniformity of measurement and are reliable the possibility of not finding suitable response alternatives can annoy the respondents (Burns, 1997). Burns (1997) suggests mixing these questions with open-ended ones to overcome this weakness. Therefore, the survey contained both closed and open-ended questions, which allowed the respondent to write freely. There were also scale type questions, which required ranking questions "by indicating degrees of agreement or disagreement". Ranking questions required asking "the order of preference among a number of options" (Burns, 1997, p. 474).

The initial aim of administering surveys was to collect general data and to look for patterns about the design process and everyone's point of view about creativity. Even though administering surveys was easy and practical there were certain drawbacks associated with the use of them, such as some students not answering open ended questions. Therefore, more detailed information was needed. Along with the observations, the interpretations of the surveys also helped to formulate the interview questions in gaining a deeper understanding.

3.5.2.3 Interviews

In order to understand others and their perceptions or definitions, one of the most efficient ways is to ask them (Punch, 2009). Burns (1997) finds that unstructured or semi-structured interviews are as important as observations in qualitative research and also that they are "more flexible and organic in nature" (Tracy, 2013, p. 139). Rather than having a specific interview schedule with a set of closed-ended questions, interviews are conducted by focusing on the "crucial issues of the study" (Burns, 1997, p. 330). In-depth interviewing is like a conversation between the researcher and the participants. The focus is on the participant's understanding of themselves and the environment. It is a free-flowing conversation without a fixed and standardized list of questions (Burns, 1997).

The advantages of interviewing are the flexibility and the higher response rates, rather than the written questions. A face to face interaction establishes a motivation among respondents. Even if the respondent does not say anything, non-verbal communication can still be observed by the interviewer. Participants feel relaxed by using natural language so they talk more intimately. The environment also allows the interviewee and the interviewer to be equal rather than be an investigator and the investigated (Burns, 1997). On the other hand, interviewing is more expensive and time-consuming. In a limited amount of time only a limited number of people can be interviewed. Another disadvantage of open ended interviewing is the possibility of the informants exaggerating or of changing reality (Burns, 1997). Including structured questions in the interviews allows the researcher to systematically compare and contrast data across participants (Tracy, 2013).

Interviews in this study aimed to get in-depth knowledge of the perceptions of both the students and the instructors about creativity issues to ascertain their experiences and suggestions. Semi-structured interviews were preferred as the aim was to start the conversation, regardless of how the questions were worded. The advantage of the interviews was that they provided the participants' perspectives rather than the researcher's perspective. The collected data were qualitative notes which were and planned to give a direction of how to go further in the research.

The instructors were interviewed for about 40-45 minutes in their staff rooms or in a library study room, which was arranged beforehand. Interviews with the instructors were made separately due to the principle of respecting every instructor's different way of teaching and interpretation. There was no pressure for them to be involved in the interviews. However, all of the instructors of the studied subjects accepted to participating.

Six instructor and four student participants were recruited into this part of the study. ME students were interviewed separately, because there was no common free time, whereas PDE students were interviewed together in one session. The interviews took about 40 minutes each and they were done in the library study rooms. A random sample of students was recruited for this study. The interview request was announced in the tutorials. Students who wanted to participate notified the author, then a suitable time was arranged for the interviews. All interviews were completed after the exam and marking periods were over to make students feel safer and more relaxed. The data were recorded on a digital audio recorder and then transcribed. The order of the interviews did not affect the result, so whenever it was suitable for the participants the interviews were done accordingly. Confidentiality was guaranteed to all the participants.

The interviews were semi-structured so participants could reflect on their experiences, thoughts and suggestions. Only the relevant part of their comments were taken. I used square bracelets like […] in interview quotations where the information was irrelevant or the English was not understood and if unpleasant language or individuals' names were used, repeating casual phrases such as "you know" or "sort of" that were not adding any value to the text were deleted.

I had the chance to have in class discussions with the students while working as a lecturer in two sections of the Product Design Engineering Studio (DPD20002) unit. I had the advantage of talking to the students about their understanding and motivation for creativity during class hours. So in these cases no further interviews were needed with the students.

Survey questionnaires and interview questions were pro tested by three academics, one with a PhD in industrial design, one with a PhD in probabilistic design and one with a PhD in sustainable design – all having published papers in design education. The design of the interview questions was based on the data collected earlier. Points that were hard to observe and understand were prioritised. However, the nature of the interviews allowed the researcher to ask some additional questions if new points of conflict emerged during the conversations. The advantage of such a method provided a friendlier conversation environment and the participants did not feel that they were questioned but just exchanging ideas. I did not comment on their given responses and stayed silent as much as possible.

3.6 STAGE 2: ACTION RESEARCH IN ME DESIGN UNITS

Depending on my constructivist epistemological perspective my methodology in this research is to choose the right methods to attain data from participants. The literature (Burns, 1997) suggests Action Research as a convenient method in this type of situation, where the aim is to change things. Altrichter et al.'s (2002) description of Action Research as an "enquiry with people, rather than research on people" aligns with my epistemological approach, that sees the researcher building the knowledge with other people. In this research, I constructed the knowledge together with the people I studied. Even though the use of Action Research is still relatively rare in engineering education it can be an effective methodology in engineering faculties (Case & Light, 2011).

The aim of this Action Research is to foster creativity, to nurture students' creative thinking skills in the design process and to help instructors in their teaching method to enhance students' creative thinking abilities. I undertook this research approach in the engineering design subjects of ME by initially framing the Action Research with the help of the literature and discussing the issues with the unit convenor (UC) and instructors of the subjects to make possible alterations. All suggested actions are discussed with the unit conveners of the subjects. After a proper agreement, the actions were implemented. During this stage two types of interventions were implemented -

general ones that concern the whole unit and weekly ones that are designed and implemented weekly. Then I became involved in the subjects to observe the situation and to assist the instructors in setting up the interventions. Finally, the collected data was interpreted to understand the effect of the interventions. This process helped the reflective phase of the cycle, as shown in Figure 3.3.

3.6.1 Data Collection and Comparison Between the Cases

The Action Research was conducted in two different ME design subjects in two consecutive semesters. The unit convener, the instructors of the units and almost all the students were the same in both cases. It gives a wider perspective to see both Action Research cases as a whole.

The reason for the choice of MSD and MD units was that they were the only design subjects which were believed to represent engineering design in the Mechanical Engineering course, having both lecture and tutorial divisions addressing a design problem-solving process.

Machine Design (MEE30003), which is a 3rd year subject, was studied throughout the 1st semester in 2015. Mechanical Systems Design (MEE40002), which is taken by 3rd and 4th year students, was studied throughout the 2nd semester in 2015. The number of contact hours and the instructor / student ratio is the same as given beforehand in section 5.2 of this chapter. Data were gathered from multiple sources at various times during the 2015 academic year.

These are the data collection methods and number of participants:

- ME - Machine Design (MEE30003)

  Observations in 2-hour p/w lectures and in two different 2-hour tutorials for 12 weeks

  Interviews with 5 instructors

  Interviews with 4 students

  Student Written Surveys with 60 students

  Note taking in weekly discussions with the instructors and the students

  Notes taking in weekly meetings with all the instructors of the unit

Student Online Surveys

Swinburne University Student Feedback Surveys

E-mails of the unit convener

- ME - Mechanical Systems Design (MEE40002)

  Observations in Mechanical Systems Design tutorials, 2 hours p/w for 2 weeks

  Interviews with 5 instructors

  Note taking in weekly meetings with all the instructors of the unit

  Examination of reflective reports of the students

  Student Online Surveys

  Swinburne University Student Feedback Surveys

  E-mails of the unit convener

3.6.2 Data Collection Methods

Carter & Little (2007) see methodological fundamentalism, which is believing "one true" research method should never be changed, as problematic. I initially used research methods such as observations, surveys and interviews. Then I expanded my methods to access more data and had weekly discussions with students and instructors, and reviewed online surveys and student feedback surveys.

3.6.2.1 Observation

During Action Research, I aimed to collect evidence about the impact of the actions taken in studied subjects. To evaluate it thoroughly, the most effective method was observation. Like Action Research itself, observation plans were flexible and open to "unexpected situations" (Kemmis & McTaggart, 1988).

During the Action Research done in MD two different tutorials were observed. Even though the aim of the Action Research was not changed the observations were minimised in MSD, which took place the following semester because it was observed that my participation affected the behaviour of the students and the instructors. This will be explained in Chapter Five. Therefore, I preferred to remain in the background as the researcher and not be visible in the later research.

3.6.2.2 Student Written Surveys (SWS)

During week 10 a similar survey questionnaire (Appendix XIV) was submitted to the students in the beginning of the MD lecture in 2015. The survey questions were previously done in MSD. The response rate was high; 60 of the students returned it from a class of 65-70. The questionnaires were completed and returned by 34 Mechanical Engineering students, 6 Product Design Engineering students and 20 Robotics and Mechatronics Engineering students.

The aim of administering surveys was to collect data about the design process and everyone's point of view about creativity. There were both open-ended and closed-ended questions. However, open-ended questions had a lower response rate than the closed-ended questions.

3.6.2.3 Student Feedback Surveys (SFS)

At the end of the year, the unit convener sent all the students the results of the SFS survey that is conducted by Swinburne University. These were all examined. The basic questions in the survey that were considered in this study are:

- In my opinion, aspects of this unit that could be improved were…
- In my opinion, the best aspects of this unit were...

3.6.2.4 Student Online Surveys (SOS)

There were anonymous online surveys of the studied units (MEE30003 and MEE40002), which were prepared and conducted by the UC with the aim of getting student feedback during the semester so as to be aware of student needs or any other issues in order to solve them immediately. This feedback also helped to make modifications in the unit content where necessary for future applications.

People who were registered in the subjects could access the results of the surveys through Blackboard. These surveys included valuable student feedback about the units that helped in my research. Therefore, I included them in my ethics application so I would be able to use the anonymous data there. The questions in the surveys were:

- Do you like the teaching staff?
- Do you like the subject material?
- Are you satisfied with the teaching quality?
- What do you like about the subject and think should be kept?
- What do you dislike about the subject and think should be changed?

The text taken from the written, feedback and online surveys (SWS, SFS, SOS) and the transcripts of the interviews were taken as they were.

3.6.2.5 Interviews

ME instructors were separately interviewed about 40-45 minutes in their staff room or in a library study room. The ethical issues remained the same as before.

ME students were interviewed two at a time. "Group interviews can make an important contribution in education research" (Punch, 2009, p. 147). The reason for that was that I wanted to talk to students together who dealt with the same design problems during the semester. The interview sessions took about 30 minutes. The recruitment for the interviews and the ethical procedures were done as before. General interview questions for instructors and students can be found consecutively in Appendix V and XVI.

During the Action Research in MD all the interviews were recorded. However, during the MSD Action Research, the same instructors had already been interviewed before. Therefore, in order not to force them to have additional formal face-to-face interviews I accepted their choice of method and time of interviewing. Instead of doing long session interviews I preferred to get in touch with them a few times during the semester to learn about their experiences when they were still fresh. I used phone interviewing, small discussions over coffee and regular question-answer e-mails. The reason of using many tools to collect data was to get as much data as possible from them by giving them the flexibility of choosing convenient times and methods for themselves, so that they would be more cooperative. Some of the instructors had work or family commitments so I accepted their preference of interviewing method, but always sticking by the ethical responsibilities of anonymity and confidentiality.

There were also underlying beliefs of the participants. Burns (1997) defines this as "hidden meaning", "reading between the lines" (p. 339), where the data is not that obvious, but hidden. That is why participants were asked additional questions in the follow-up phase of the study to understand the hidden meanings that the researcher was unable to clarify.

3.6.2.6 Note taking in weekly discussions

Weekly class discussions involved routine chats between me, the students and the instructors. During the observations in MD all these weekly conversations about both parties' experiences in class were noted afterwards. These notes helped in later formulating the survey and interview questions.

3.6.2.7 Note taking weekly instructor meetings

All MD and MSD instructors participated in the weekly half hour meetings in the UC's room throughout the semester. Anyone who missed a meeting was given a meeting summary. The aim was to discuss their reflections on the previous weeks and on their plans for the upcoming weeks. During the Action Research period I participated in all these meetings and took notes to learn about the instructors' views. These meetings allowed each participant to benefit from others' experiences.

3.6.2.8 E-mails of the Unit Convener

The UC sent e-mails to students periodically almost every week of the semester. The nature of these e-mails was to inform students about the deliverables, requirements, any issues raised or some personal suggestions on how to better achieve in engineering design subjects. I received and examined all these e-mails.

3.7 OVERALL ANALYSIS

This study used the organisational culture theory described in section 2 of this chapter. During the analysis, I depended on the levels of organisational culture: Artefacts, Values and Assumptions and Beliefs (Schein, 1984).

I used and analysed my dataset by using organisational culture theory to enhance creativity in engineering education. The first step of the analysis was to examine the artefacts. These were the things that are already available, visible or audible: The behavioural patterns of students and instructors, minutes of instructor meetings, all the observations done in lectures and tutorials, teaching and learning materials such as the unit outlines and rubrics.

Then, the second step of the analysis was to access the values of the instructors and students. In order to understand the observed practices of the participants I reviewed the written survey results and interview transcriptions in addition to examining the student feedback and online survey results. These were the things that we cannot measure directly but need to interpret. At this point, the analysis of the data collected from different disciplines (ME and PDE) were done concurrently but separately as they had different values. Therefore, I came up with the complex model of my organisational structure of the study as shown in Figure 3.5.

The final step was to do a further level of analysis to access the beliefs of the participants. These were the assumptions and underlying beliefs that established their values. They were the taken for granted things, the accepted preconscious beliefs or reflections of previous experiences. There was not a direct method of measuring them. They could only be accessed by interpretations. In order to access these "hidden meanings" as described by Burns (1997), follow up interviews were carried out and interpreted.

From an interpretive perspective, as in any research, collecting the data and analysing the data are both important. I covered a vast amount of the literature on creativity in engineering education, so I accessed a level of expertise to analyse the data. I made detailed records of my own participation during the observations and used these experiences as important data sources in analysis. I started analysing the data immediately rather than waiting to collect all of it. The first stage of the data (Chapter Four) was interpreted by following the sequences of Soft System Methodology steps as mentioned previously.

Collected surveys were put in Microsoft Excel software to examine the statistical results. All the interviews were transcribed. The observational notes and the minutes of the meetings were reviewed repetitively by considering the main themes that emerged during the observations. The analysis process started by examining the students' and instructors' responses by looking for similarities and differences and by coding the information into categories. There were no significant pre-determined categories. However, within time, the responses gained from the survey questionnaires and the interviews blended with the insights gained during the observations and helped with categorising the issues more specifically. The common and repeated themes were taken into consideration (such as lack of guidance during the design process or motivation for creativity). I also read through all the emails, notes taken during discussions, and the results of online and feedback surveys. After examining the missing information about the results, additional investigations were planned and conducted in order to gain enough evidence to support the findings.

For the second stage of the study (Chapter Five) students' and instructors' comments were taken into consideration to understand the effect of actions done in design units. The instructors and UC being in the teaching position, the author being in the observer and researcher position and the students being in the learning position all reflected on their experiences and all of these comments and reflections are evaluated and interpreted to help in deciding the effect of the actions taken. In order to describe the influence of the interventions, comparative interpretations and reflections of the participants were considered. Instructors have years of experience in teaching the same units, so they have the expertise of comparing the present and the past situations of the creative process during problem-solving. In depth interviews were also done with the students in an attempt to get additional insights.

Even though I started investigating creative pedagogy in engineering during the design process from the perspective of three aspects described by Lin (2011) and Zhou (2012a) — Instructors for creativity, Tools for creativity and Environment for creativity — there were also new issues to address. The interpretations did not only address the answers to the research questions, but also revealed new points of conflict for further investigation. During the analysis process, where new issues were identified, relevant literature was reviewed to be able to gain knowledge about these unexpected aspects.

When writing the findings of the study I integrated the interpretive approach with the positivist approach as suggested by Lee (1991). Three levels of understanding were used: The “subjective”, the “interpretive” and the “positivist” understandings (Lee, 1991). So, after examining the issue, every claim that has been made was substantiated with evidence and warrants in order to logically support the arguments and to make sense. The epistemological approach, the methodology and the research methods of this research is summarised in the table below:

Table 3.1 Methodology and Research Methods of the Study

Epistemology	**Theoretical Perspective**	**Methodology**	**Data Collection Methods**
Constructivism	Interpretive (integrated with the positivist approach)	Soft Systems Methodology Action Research	Observations in class Interviews with participants Weekly regular meetings with UC Weekly instructor meetings E-mails with instructors and UC Student online surveys Student written surveys Student feedback surveys Artefacts examination (Online learning materials such as Unit Outlines, Assignments, Rubrics and etc.)

4 CHAPTER FOUR: EXPLORATION OF THE CURRENT SITUATION OF CREATIVITY IN ME AND PDE

4.1 INTRODUCTION

Chapter Four provides an important opportunity to advance the understanding of creativity from different perspectives; in this case from Mechanical Engineering (ME) and Product Design Engineering (PDE) perspectives. This chapter seeks to extract data that will help to address the gaps in creativity in ME.

Considering the suggestion of de Vere (2009) that engineering should look to design pedagogy as a model for enhancing creativity and innovation, it is assumed that PDE would give clues in promoting and enhancing creativity in engineering. Taking this approach, this chapter begins by revealing the context of the study. It will then describe the current situation in ME and PDE, aiming to contribute to the growing area of research by exploring how creativity is understood in different disciplines of engineering. All findings in this chapter came from the observations, surveys and interviews throughout the 2014 and 2015 educational years in the subjects being investigated. The issues highlighted in this chapter, along with the data gained from the literature review, were used to conduct Action Research in ME design subjects with the aim of enhancing creativity by leveraging the findings in PDE education.

The study aims to investigate what aspects are used in PDE education to foster creativity that could be transferred to ME. This will be done by discussing the suggested actions with the unit conveners and the instructors of the chosen ME design subjects. Therefore, the reader should understand that not everything was copied from PDE; only the things that it was thought to be efficient in an ME context were highlighted, discussed and then the appropriate ones implemented.

Sections of this chapter have been published and presented as a paper at the IASDR Conference in Brisbane, Australia (2015) and the 27th AAEE Conference in Coffs Harbour, Australia (2016).

4.1.1 Approach

This chapter aims to address the following questions:

- What problems are there with teaching of creativity issues in the engineering design subjects and what needs to be done to remedy these problems?
- What is the best environment and best instructor approach for the teaching of creativity and learning in an engineering design education context?
- What kind of methods are currently used to foster creativity in engineering design subjects?
- What aspects of creativity are used in PDE education to foster creativity that could be transferred to ME?

In order to get a deeper understanding of these issues, interviews and surveys were required along with observations to see what is in engineering curricula at the moment in relation to creativity and how the structure of engineering subjects influenced student behaviour. And also "how creativity and innovation are approached in the classroom and offer strategies to make creativity a part of every engineering curriculum" (Stouffer et al., 2004).

Therefore, this study looked at instances of creativity, creative thinking, the use of creative methods, creativity barriers and blockers, perceptions of creativity, the relationship between students and instructors and the effect of the classroom atmosphere. The aim is to understand the current situation both from the perspective of engineering instructors and from the perspective of students. Especially at this stage of the study where the studied organisational culture is cross disciplinary, as the participants were coming from different backgrounds: PDE, ME and also industrial design (ID). Therefore, I have tried to present the disciplines studied and the backgrounds of the participants as accurately as possible.

The chapter ends with the collected data being organised in themes and making unstructured expressions of the situation under general titles by using Soft System

Methodology (SSM) (Checkland, 2000), which was explained in Chapter Three. In this respect, the figures (Figure 4.9, 4.10, 4.11, 4.12, 4.14) created in the following sections of this chapter should be seen visual aids and representations of these themes and should be considered as a whole rather than separate representations of different concepts in engineering.

Stages 1 and 2 of SSM are still the exploration phases. Therefore, the current situation of creativity issues in engineering education are defined and the issues that need attention for further investigation are identified. During the investigation, the most interesting parts to observe were the different approaches of PDE and ME classes towards creativity and creative thinking during the design process, which in the end affected the students' performances in terms of creativity. Therefore, as much data as possible was collected and were presented in an unstructured form at this stage. As Checkland (2000) suggested, the creativity issues in design units and different approaches of two disciplines to creativity are pictured by graphs.

At Stage 3 of the SSM, the issues were clarified to comprehend the situation. Due to the complexity of addressing all perspectives as a whole, they were separately addressed as suggested by the literature (Checkland, 2000; Williams, 2005). The key points, such as design process, motivation, time management or creativity assessment are distinguished. The remaining steps of SSM will be explained in the next chapter.

4.1.2 Context of the Study

This chapter disseminates information gained through the studied design subjects in Swinburne University of Technology. Data collection Stage 1 was completed both in ME and PDE design units.

4.1.2.1 Mechanical Engineering Units

Mechanical Systems Design (MEE40002) unit is a semester 2 subject in the Faculty of Science, Engineering and Technology at Swinburne University of Technology. It is a 4th year unit. Total contact hours are 48; 24 hours of lectures and 24 hours of tutorials. The unit outlines (Appendix XVII and XVIII) say: "This unit of study aims to develop your ability to design and build complex engineering systems, understand the systemic implication of design decisions, understand design challenges and apply design theory".

Projects need to be done with a group of 4 students in a mixed team. There were five different design project options, however the majority of the students chose the Solar-boat project as that was the initial problem: “Students are to take on a project to develop a solar powered boat using the solar panels that can be borrowed from the library. Each boat will compete against the other boats in a race to one end of the pool and back held as part of the Solar Vehicle challenge at Science Works. The assessment of the design project is done in a competition format that will be based on a round robin. The score for each team will be the accumulated points from the round robin. Marks will then be allocated to each team based on a formula” (MEE40002-UO-2014).

Students were expected to describe their design process in a report. For the report, the highest mark one can get was going to be the lowest single score of those allocated to the different criteria such as introduction and background, literature, design strategy, system evaluation, concept generation, concept selection, concept analysis, documentation, conclusion and recommendations (MEE40002-UO-2014). So the final mark will be the lowest mark you get over this range. For example, if you get 5 for one section, 3 for another and 1 for another, your final mark will not be the cumulative, but it will be 1 (the lowest one) even if you achieved more in other sections.

After doing semi-structured observations in the Mechanical Systems Design (MSD) unit, surveys were administered in a paper-based form after the semester finished. They were done in two tutorials of the MSD unit, where the observations had previously been conducted. The response rate was 91%. Of the study population, twenty-one students completed and returned the questionnaire. Of the cohort of 21 students, 5 were from PDE and 16 were from ME. The response rate from instructors was 100%; they all completed and returned the questionnaires. After the surveys, interviews were done with the students and instructors towards the end of the semester. The instructors’ quotations from the interviews are referred to as ME-I1, ME-I2 etc., and the student quotations are labelled as ME-S1, ME-S2 and etc.

The Machine Design (MEE30003) unit is a semester 1 subject in the Faculty of Science, Engineering and Technology at Swinburne University of Technology. Total contact hours are 48: 24 hours of lectures and 24 hours are tutorials. It is a 3rd year unit. Similar to the process in MSDs Design, projects need to be done within a group of 4.

The main design problem in Machine Design (MD) was a ‘gear-box project’: Student teams are to design and build a gear-box from laser cut acrylic. It needs to lift a certain weight, be a certain height and it will be powered by a standard electric motor. The second popular problem was a project titled the “Great ball-handling contraption”. The unit outline describes it as “an ideal project for students who want more freedom and like the idea of something different”. Students are required to design a module to be displayed during the Open Day of the university to promote their discipline. They can use any material, technique and technologies (electrical, mechanical, civil and so on) to show aspects of different engineering areas (MEE30003-UO-2015) (Appendix XIX).

4.1.2.2 Product Design Engineering Units

Two PDE design studio units were observed: Product Design Studio and Advanced Product Design Studio. After observing, interviews were done with instructors and students. The instructors’ quotations are referred as PDE-I1, PDE-I2 and PDE-I3, and the student quotations are named as PDE-S1 and PDE-S2.

Product Design Engineering Studio (DPD20002) is a 2nd year subject. It involves 2.5 hours of studio and 1.5-hour Illustration and Digital Visualisation tutorials each week. It had two different design projects, which can be seen in Appendix XX:

Project 1: “Spork: Using the design and analysis of small plastic components you will be designing a group of cutlery for a defined demographic. The cutlery should provide the range of functions as used in a fork, spoon and knife”.

Project 2: “Inside Out: You will need to source a product for reverse engineering – most of the products listed have options available for approximately $20 for ‘no name’ brands. Your re-design will be according to a specific target market your group will be assigned” (DPD20002-UO-2015).

Advanced Product Design (DPD30001) is a 3rd year subject (Appendix XXI). It involves 2 hours of studio and 2 hours of tutorial each week. The project “is designed to explore a relatively new water heating technology, and to utilize this technology to develop new energy efficient products. Students will be working with a company; Microheat Technologies participating in a design competition to produce the most innovative solution. The primary objective of the project is to find new applications for the Microheat Water Heating Technology within an allocated scenario and to prove that the application is viable by developing a manufacturable design solution" (DPD30001-UO-2015).

When writing the thesis, no distinction between the 2nd and 3rd year PDE design units was made. They were considered as a whole, as the overall approach in both units were quite similar in terms of instructor approach, design process, creativity understanding, assessment criteria and environment.

4.2 FINDINGS AND DISCUSSION

The research findings show that there are many gaps in ME in terms of creativity, creative thinking and design process. There are also many points found in PDE education worth considering for addressing the gaps in ME education. The figures in this chapter are coming from the written survey results that were conducted in ME design units. In order to read this chapter easily, a comparative table (Table 4.1) is prepared. This table is a summary of the insights from the observations and results of the surveys and interviews conducted both in ME and PDE design units. Each item in Table 4.1 will be discussed and described further in the chapter.

Table 4.1 Comparison of PDE and ME Design Units

Product Design Engineering	Mechanical Engineering
Design every semester	Design only twice in 4 years
Ill- defined design problems	Well-defined design problems
Not competitive projects	Competitive projects
Focus is on design process	Focus is on design product
Priority is product creativity	Priority is product performance
Students believe they need to come up with creative ideas	Students believe they need to come up with working ideas
Marks given for creativity	No marks given for creativity
Instructors accept subjectivity in assessment	Instructors avoid subjectivity in assessment
Feedback is constantly given	Feedback is given when students ask for
Continuous instructor guidance	Less instructor guidance
Previous student examples are shown	Previous student examples aren't shown
Regular presentations from students	No presentations from students
Sketching/drawing is encouraged	Sketching/drawing is just mentioned
Students start design process by hand drawing	Students start design process by CAD drawing
Design folio is a requirement and assessed in the end	Design folio is encouraged and not assessed in the end
Both engineering and design instructors	Only engineering instructors
Instructor/Student ratio is 12/2	Instructor/Student ratio is 20/1
Class hours for idea generation	Class hours for technical questions
Creative and design tools are introduced and used in class	Creative and design tools are mentioned but not practiced in class
Students are relaxed	Students are stressed
Students do not afraid to fail	Students afraid of failing
Students take risks	Students avoid risk taking
Students organise the class setting for better communication	Students do not organise the class setting
No exam	An exam in the end
Students focus on the design project	Students focus on the final exam
Motivational industry speakers	Discouraging industry speakers
Promotion of creative thinking	No promotion of creative thinking

4.2.1 General Situation in ME and PDE

In ME tutorials, the general conversation was about technical issues, exam questions, tests, framing, writing reports and performance of designs. Instructors gave critiques and highlighted the important points that students needed to consider. However, in PDE design classes, students usually got feedback on how to develop their project ideas.

One survey question asked how creative the respondents thought they were in general and how creative they were during the MSD unit. They were given a scale of 7 to 1. 1 is for "not at all creative" and 7 is for "highly creative". Figure 4.1 illustrates both the level of general creativity and the level of creativity in the unit.

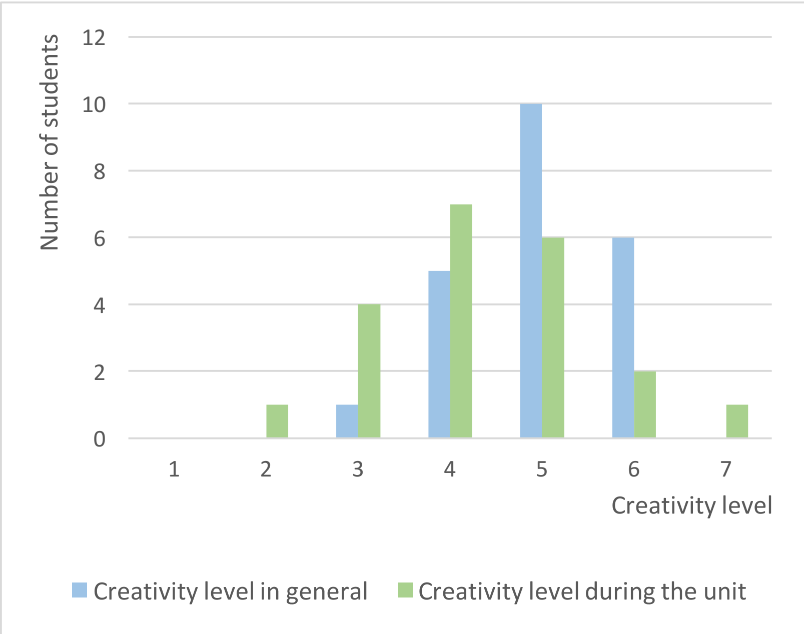

Figure 4.1 Creativity level in general and during the unit

When all the responses were analysed one by one as shown in Figure 4.2, almost half of the students think their creativity in general and during this unit were at the same level. Even though one third of the students think their level of creativeness in the unit is less than their general creativity, the difference of the levels they indicated were not significant. Therefore, it can be said that the students think they were as creative in this unit as they were in their daily lives.

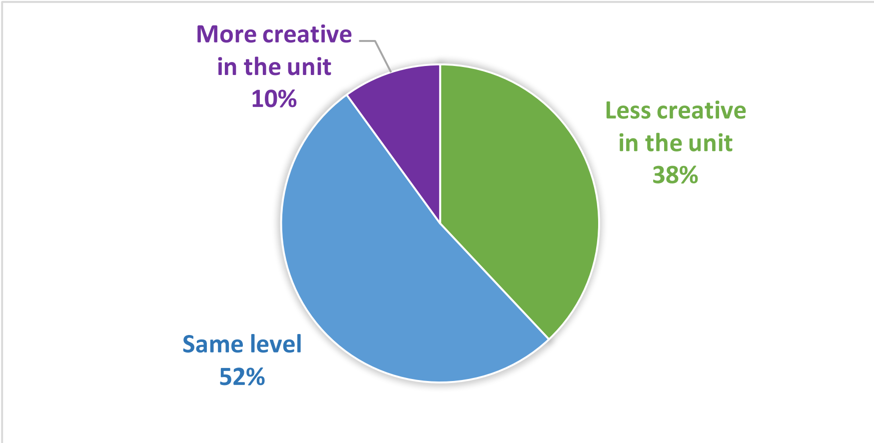

Figure 4.2 Students' creativity in general vs. their creativity in MSD unit

The instructors were given a scale of 7 to 1 -1 for "not at all" and 7 for "highly creative"- for deciding how creative their students were during the MSD unit. Another question was asking how successful the subject was in helping students develop creative skills, again with a scale of 7 to 1 -1 for "not successful" and 7 for "very successful"-. The results do not justify a graph as the small numbers were not statistically significant; the average of both the responses were between 5 and 6. This data shows us the instructor thought that this unit reached its goal in developing creative skills.

An open-ended question was asked of students about the most effective lecture, week or assignment during the semester. It was determined after reading all the responses in the survey that half of respondents thought that designing and building the Solar-boat was the most effective part of the unit. When ME instructors were asked about the main purpose of the unit, the responses were "to get the students to a level where they can be reflective of their own design ability and have an idea of what they need to do to get better" (UC), "to understand the balance between formal methods and informal methods" (UC), "to understand what design is" (UC), "to think systemically" (ME-I1), "how to document a report" (ME-I1) and "to design a system" (ME-I3).

One significant difference between the approaches of ME and PDE was the exercise of showing previous examples to students. PDE instructors showed many examples to students in class; presentation samples, graphics, renders, good and bad examples in order to make the students understand what was expected from them in terms of quality and creativity. On the other hand, ME instructors were hesitant to show anything and the reason for that was indicated by the unit convener. S/he said that they had tried it, they showed previous year's students works to students and in the end they observed that students got fixated on what they were being shown and came up with the exact same ideas. Jansson and Smith (1991) confirm that, the reason of fixation in a design process might be caused by given examples for design problems.

PDE-I1 was asked about how s/he positions PDE in the engineering faculty. The response was "Students are part engineer, part designer. PDE is very applied engineering. I see the vocational part as very much applying that theory to a creative process of product development" (PDE-I1). After examining PDE curricula globally, de Vere (2013) reports that the "PDE model has a flexibility and responsiveness not possible within established engineering curricula such as ME. The PDE model sacrifices depth in engineering knowledge and analysis to incorporate the design curriculum and its key agendas, but this is balanced by the resultant broad skills base and extended capabilities of graduates" (p. 361).

Another interesting difference between the PDE and ME instructor approaches was their relative expectancy level from students. PDE instructors see the students as students, however ME instructors expect the students to behave more like professional engineers. Both sides have valid arguments though. ME instructors tried to prepare students for the industry and real life conditions, which is why they expected professionalism form students. On the other hand, PDE instructors indicated that this was still a learning process in an educational context and therefore they showed some flexibility. However, they didn't forget to warn the students that professional life does not accept mistakes.

In MSD, students were asked about their learning styles resulting from the VAK Learning Style test (Appendix XXII) they had previously completed at the beginning of the semester. This test, in which students describe themselves, was provided to the students by the unit convener as part of the MSD subject. Although many schools use this test, there is still little evidence about the validity (Evans & Sadler-Smith, 2006). It was suggested for students to do with the intent of having a general understanding about themselves. The majority of the responses from the students was that they were people who learn from doing things (Figure 4.3).

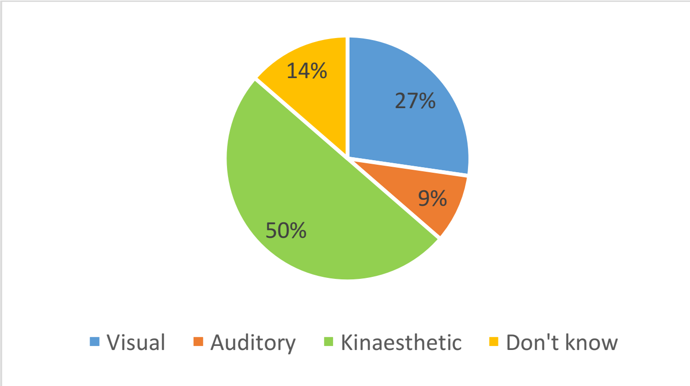

Figure 4.3 Student responses to learning styles in MSD

The current study found more differences rather than similarities between the delivery of the design subjects of the ME and PDE disciplines. One of the survey questions (2014-MSD-SWS) was designed to be answered only by PDE students, due to their experience in both PDE and ME design units. The question was to describe the differences between the units. One individual stated that “ME is more about performance and optimisation, and PDE is more about design and human interaction”, and another commented “PDE classes are much more creative with a larger workload, ME design classes are more rigid with less workload”. Similarly, another comment was “PDE has much more creative solution-based subjects while ME has more machine/scientific ‘yes’ or ‘no’ type designs”. Another student responded with this distinction: “Mechanical engineers tend to rely on what already works and seek to improve that, Product design engineers are constantly striving for a new/better idea”. Having identified the general situation, the classroom environment will be described.

4.2.2 Classroom and Studio Environment

MSD and MD lectures were done in a large lecture hall, where there was adequate seating and lighting. The length of the lectures were two hours once a week; mostly they were conducted as a block, sometimes a five-minute break was given, but usually students preferred not to go out. Instructor told the relevant information in front of the lecture hall with the help of a projector by showing students power point notes, graphs or mind maps. There was always a time for students’ questions, but it was never like a group discussion as the number of students was more than 100. Lectures were focused on giving information on issues such as problem framing or design methods, whereas tutorials were for seeking information. For 170 students there were 8 tutorials, so the number of students in each of them was expected to be over 20. However, in practice the number of students changed between 5 and 20 in the observed tutorials. The length of the tutorials were two hours and they were always conducted as a block with no break. In the first half of the tutorial, instructors lectured at the front, usually showing power point notes. Then there was time for group discussion and asking questions. The general feeling in the tutorials was usually relaxed and the environment was friendly. Instructors were organising tutorial time according to the needs of the students and because students were more worried about the tests and the exam these concerns were taking most of the time.

Both ME tutorials and PDE design subjects took place in traditional classrooms where there were 12–15 large tables and around 25–30 chairs. So if one wanted to, it was actually easy to turn the classroom into a 'studio-like' environment. However, there was not a typical seating plan. The organization of the chairs and tables in the classrooms was different each week, which made it hard to organize a suitable seating plan for group discussion. Students tried to sit together with their team members each time in a different place and organisation. However, neither the ME students nor the instructors ever attempted to change and organize the seating plan according to their needs.

Another point worth mentioning is the ratio of students to instructors in the different disciplines. In PDE this ratio was about 12 to 2, however in ME it was 20 to 1. In PDE, students had the time to get longer and more in-depth feedback, which accordingly enhanced their motivation. The reason for this was because PDE requires a design lecturer and an engineering support lecturer to satisfy requirements set by the governing body, Engineers Australia.

It was observed that when there were more than 20 students the classes needed to be organised in a more appropriate manner, allowing everyone to sit in groups and discuss their work, as most of the projects required teamwork in both disciplines. Even though PDE uses traditional lecture format classrooms in which everyone is facing the board, when it came to "desk critique" or group discussion, students themselves arranged the tables in a more appropriate way to assist this.

In ME tutorials, ME instructors tried to see each team once during the classes to give them critiques about their projects, especially on technical issues, if students were willing to talk about their projects. Then, when the students finished talking with their instructor they tended to leave the class. Some students had a habit of coming late every week and leaving early, whenever they were done. It made it hard to concentrate for the others as the door was always opening and closing. This behaviour was rarely observed in PDE studio classes. Students usually stayed until the end of the classes each week. Even after students had talked about their projects with their instructors they preferred to spend the rest of the class hour listening to talk about other projects and participating in discussions. The reason for that were the different expectations from the instructors. In PDE design units, instructors always reminded and encouraged students to listen to the others and to comment on the other projects. However, that was not an expectation in ME.

An open-ended survey question was asking students to describe a classroom setting in which they think they would be more creative. They generally described an ideal place for more creativity. An open space design with modular desks which gives the flexibility for a group discussion arrangement where everybody can face each other. This view is also supported by the instructors. ME-I1 believed that a classroom where the teacher just stands and talks is not good for creativity, so s/he (ME-I1) tried to make students sit according to their groups by facing each other for a group discussion. UC believed that expectation of creativity would actually encourage it rather than the structure of a physical environment. S/he adds that a physical environment which is suitable for all kinds of students is not possible, as everyone's requirements are different. ME-I3 suggested using a round table format in the classroom, so that the groups can face each other. However, s/he admitted that s/he did not arrange the tables like this because the class was so small. Although PDE students helped in changing the classroom setting before each class, PDE-I1 found some classrooms inadequate for group work: "I find that it doesn't allow the face-to face group work. I try to move the tables. I was trying to make people sit around the tables and look at each other. There's no place to pin up the work. It doesn't provide the typical studio facilities like pin-ups, critics, group work" (PDE-I1).

In summary, if a more appropriately configured design studio was provided for ME tutorials, which allows a proper seating plan for a group discussion, it is believed this would enhance the creative process, as current configurations are not suitable. A design studio should be provided for tutorials, or at least the seating plan should be arranged according to the needs of the class before each tutorial to assist the creative process. Prior studies have also noted the importance of a "design studio setting" in design education (Ferreira et al., 2014). Lawson (2006) highlights that the major advantage of a design studio is the "one-on-one desk critique" and Goldschmidt et al. (2014) defines the design critiques as the "bread and butter" of studio activity and design education.

4.2.3 Understanding of Creativity and Design

It is worth explaining that the first step was to clarify the understanding of creativity among instructors and students. The survey results, done in two consecutive educational years, show that students' understanding of the key concepts of creativity harmonize with instructors' perspectives. These observations inhibit any possible misunderstandings about creativity concepts between the instructors and the students.

In response to the survey question "What creativity means to you?", the responses from ME instructors were, "to bring something forth", "thinking outside the box, being able to synthesize ideas to produce something original" or "expressing imaginative ideas into reality". The prominent responses to the same question from the students were: "Open mindedness", "expressing yourself", "exploring", "innovative", "making new stuff", "making useful, different things", "original", "creating something from nothing", "seeing something from a different angle" "to look at something from multiple ways", no boundaries", "no fixation", and "improving existing solutions". Creating is described as "an ability to come up with something new and interesting", "an ability to create non-standard solutions and outcomes" or "thinking outside the box to solve problems or improving existing solutions" (2014-MSD-SWS).

In the given survey, instructors and students were expected to choose the properties that they think represent a creativity/creative output in an engineering context. Figure 4.4., 4.5 and 4.6 show the responses to the question. Among the given characteristics, the majority indicated that "innovative" represents creativity.

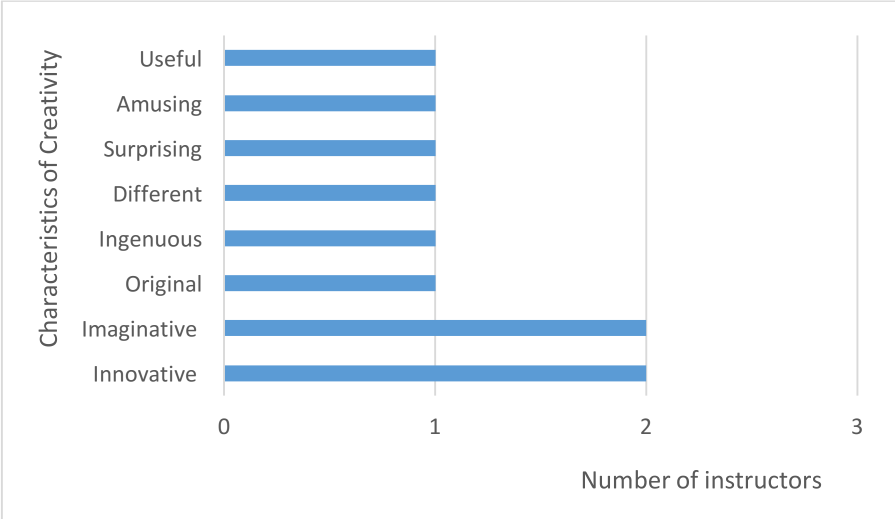

Figure 4.4 Characteristics of creativity – Instructor responses 2014

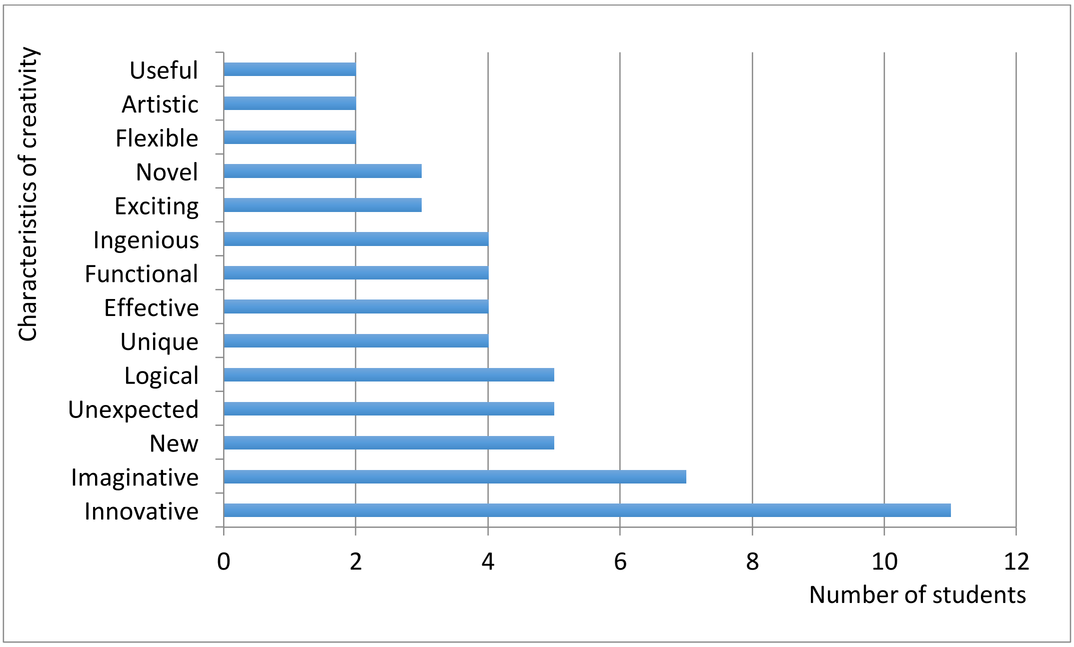

Figure 4.5 Characteristics of creativity – Student responses 2014

Just like the students of 2014, 2015 students' first criteria for creativity is "innovation", which has been chosen by 39 students out of 60.

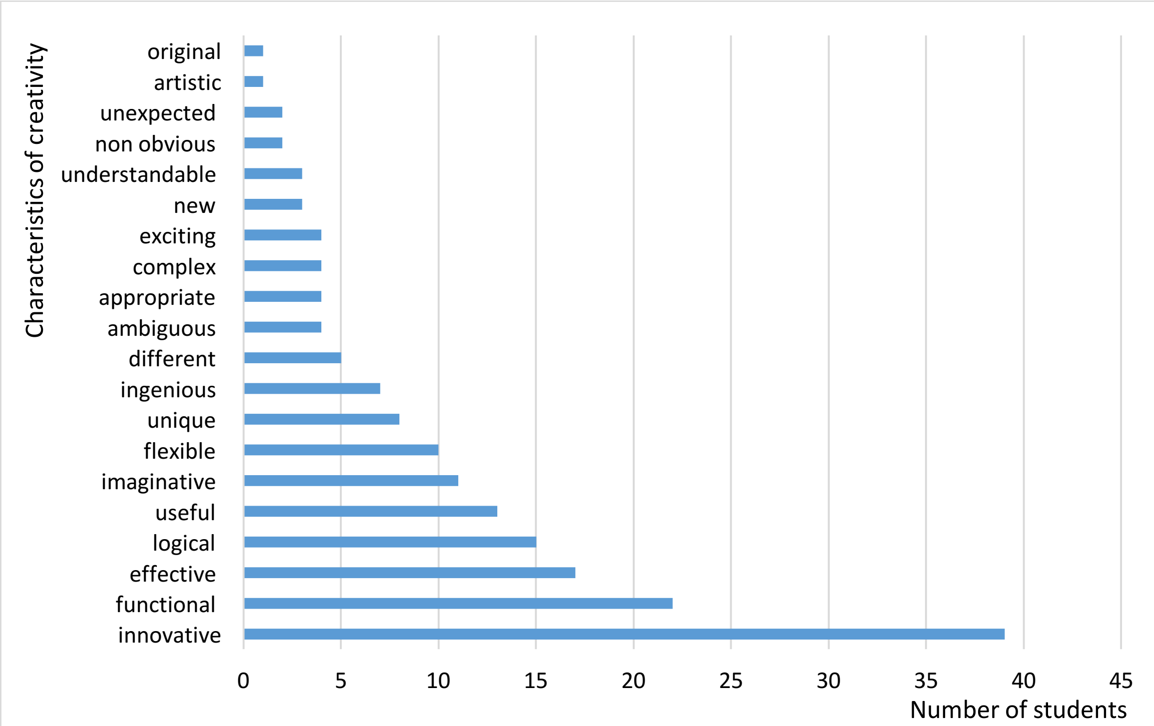

Figure 4.6 Characteristics of creativity - Student responses 2015

To the question of "do you think an engineer needs creativity?" 59 of the students replied "Yes" and there was only 1 "Not sure". The next question was asking whether students think they were expected to be creative in the MSD unit. This time 52 responses were positive, 2 of them were negative and 6 of the students were not sure (Figure 4.7).

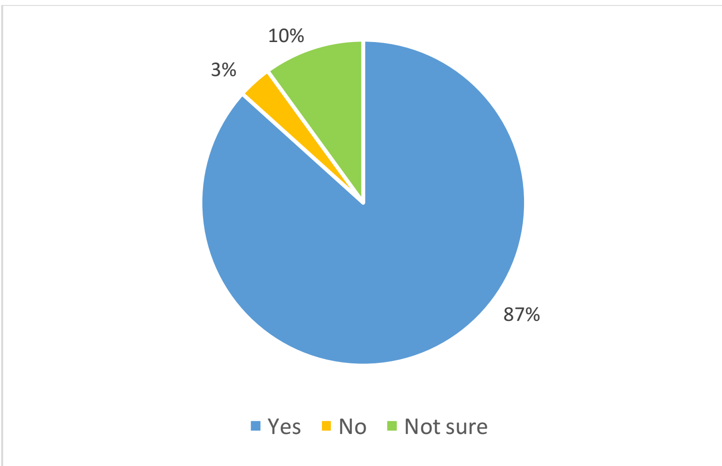

Figure 4.7 Do you think you were expected to be creative in MSD?

When instructors were asked about the key components in a successful creative process, responses included: "wanting to solve it", "time", "openness", "the use of effective assessment", "motivation", "creative thinking skills", "curiosity", "risk-taking", "a resource pool" including concepts, theories and first principles. Students indicated "opportunity to engage in challenging discourses that allows students rethink their traditional views" and "to apply what has been learned and to reflect on what can be done better" and what can be achieved by a suitable environment for creativity (2014-MSD-SWS). The present findings seem to be consistent with previous research. "Motivation" is seen as necessary as a personal attribute for creativity by many researchers (de Bono, 1993; Amabile, 1983; Torrance, 1987; Sternberg & Lubart, 1996; Piirto, 2011). Similarly, there must be risk taking (Sternberg, 2006; Piirto, 2011; Sahlberg, 2009) for achieving creative results. Several studies specify "building a suitable learning environment" as essential for creativity too (Zhou, 2012a; Lin, 2011; Rhodes, 1961; Sternberg & Lubart, 1996; Treffinger et al., 2002).

The UC clarifies the difference between designers and engineers: "Design comes from the Latin word 'designate'. Designer is the person who says this is how it would be. Design is the process of designating what form something will take. Engineering is the balance between practicality and creativity, which is what we call 'ingenuity', which is where the word engineering comes from". ME-I1 defines design as "the art and science of making things", ME-I4 defines it as "bringing forth an idea to something that is functional" and adds that "If there was no creativity, we wouldn't have mechanical engineering" (ME-I4).

When it was asked (2014-MSD-SWS) whether or not an engineer needs creativity, all instructors were positive about it. The reason for that was "the structure of some problems that needs novel approaches and ideas to be solved". That is why an engineer needs creativity and it "should be a key skill for any engineer or designer". When students were asked whether they think an engineer needs creativity and if it was important in their engineering education all the respondents answered positively. The reasons were "because engineers should come up with things others can't", they "need to solve unexplored things", "to find new ways to solve a particular problem" and "to create or build a new product and improve it". Creativity "allows engineers to further develop new and existing technologies" and "without it, the boundaries of engineering wouldn't be pushed to problem solve". 95% of the students agreed that creativity was important in their engineering education.

ME-I4 gave cooking as an example of creativity when the instructors were expected to describe something creative. After the 1980s and 90s when more allergies arose, there were more constraints and limitations which ended up producing more creativity (ME-I4). ME-I3 emphasises the "surprising" aspect of creativity and gives the Mendeleev table as an example. The UC declares that "something is creative when you've been able to look at it from a perspective nobody has actually considered. You bring things together that other people haven't actually thought beforehand" (UC). ME-I5 outlines the different possible solutions to one problem. PDE-I3 supported this by saying that "being creative is broad thinking, coming up with innovative solutions, looking at solving problems in unique ways". S/he added that "innovation which I put hand-in-hand with creativity can come in any field of engineering. I think sometimes it requires the lecturers push the students to think beyond the square, trying to reach not the same answer all the time, but coming up with alternatives. Creativity and innovation can come in different ways" (PDE-I3).

PDE-I1 made an interesting comment that "engineers don't understand problem-solving as being creative. Anything you might use a number of strategies for to solve a problem is creative, even though it might not be termed as creative. I see problem-solving as being creative, because you come up with a new solution for a problem that might not have existed before […] The process to come up with that idea and the process of getting all these different people to come together to actually synthesize their ideas into one racing car is a creative process" (PDE-I1).

It is apparent from all the instructors' perspectives that the definition of creativity is not perceived differently by PDE and ME instructors. According to some ME instructors, creativity is "sometimes" needed for some type of problems, whereas PDE instructors think students always need to be creative throughout the design process. The UC highlighted that the biggest challenge during the problem-solving in a design process was "students understanding of when they should be creative" (UC). On the other hand, ME-I1's summary was that students need creativity in framing the problem, in generating ideas, in selecting the best idea, then in developing the one you've selected and in the end for balancing all of them, in short, throughout the whole design process.

4.2.4 Promoting and Developing Creativity

The amount of creativity and creative thinking encouraged and developed in the studied units was investigated. The overall response to the question (2014-MSD-SWS) whether creativity was promoted or not in the unit was very positive. All instructors agreed that it was promoted, “but not in the sense that it’s the most important thing” (UC). All ME instructors agreed that they did not give any credit for creativity. “In core it has to be a part of it, but in practice it was just a bonus” (ME-I1).

In response to the question as to what the instructors had done to develop students’ creative thinking abilities, ME-I1 believed, some of the problems given to students encouraged them to come up with many ideas for solutions: “It helped them to explore problems and to understand what the problem really is” (ME-I1). UC explained it in four steps: First of all, setting the project in an open-ended way gives students a challenge that requires creativity. Secondly, there needs to be an explicit reference to creativity in the project report. Thirdly, some basic creativity tools are covered in class. Finally, putting students in mixed teams encourages them to see the problem from different perspectives and that also enhances their creativity (UC). However what UC mentioned is the ideal situation. The problems were not very open-ended when compared to PDE problems, as the final product is obvious from the beginning: “a solar powered boat” or “a gear-box”. Secondly, creativity was just a section of a report that students need to write after the whole process ends. Thirdly, creativity tools were mentioned in class for no more than just 20 minutes in one lecture, without any practice, and it was expected that students would learn and apply them all by themselves. Finally, putting students in mixed teams encouraged the ME students to solve the technical problems and leave the creativity part to the PDE students, because they believe PDE students are better at creative thinking. When talking to students during the observations, they said they were very happy that they were having a mixed group, so that the ME students could solve the technical issues and the PDE students could come up with new ideas. This planned ‘ideal situation’ is actually not ideal.

The ME students' responses to whether creativity was taught and promoted in the unit had an equal number of "Yes" and "No's". A few students noted that creativity "is a hard topic to teach" and added "it cannot be taught" but one became "enlightened upon experience", "promoted" or "inspired through brainstorming, concept generation and framing". One student responded that "instructors did not teach creativity but rather taught how to structure design". Another student indicated that they were "marked on success, not creativity, thus the risk of creating a creative design is too high". In response to the second part of the question, "How could creativity be better developed in the unit?" there were various suggestions like "doing more creative exercises", "requiring creative approach to solve problems", and "using a series of smaller projects". Other responses were related to increasing group activities in tutorials, emphasizing discussions as a group or "promoting creative thinking".

When it comes to motivational sources, there was also a distinction between the disciplines. Students met professionals from the industry as guest speakers. They paid attention and were more attentive to what industry guests have to say, as these people were coming from the 'real world' in comparison with the university environment. In ME, guest speakers from the Victorian Model Solar Vehicle Challenge visited the class. they used really discouraging words when describing the project such as "really tricky", "hard", "difficult task", "challenging', "not easy", "are you prepared to take that risk". Whereas PDE guest speakers emphasised that engineers need to "look from a wider perspective", "look more broadly" when designing, which was a more encouraging and inspiring speech and not as threatening.

PDE instructors were asked if they needed to indicate and remind students that creativity was expected from them. PDE-I2 stated that "it is important to remind them about what is new and novel […] Creativity's a very tenuous line […] You have to be careful about the expectations and where you want to try and lead various students […] So they can push themselves hopefully to come up with more designs, more new and novel designs […] It's always a challenge that we've got to try and push them to create new ideas" (PDE-I2). PDE-I3 preferred to tell them "to go creative go crazy and then come back to reality. I do encourage being creative through the whole process […] Sometimes you locked on something, it is also good to focus on the resolving for the manufacturing process. There is always room for improvement with every design".

PDE-I1 kept saying to students that the customers will not pay to get a product that is already in the market. S/he constantly reminded students to think creatively. ME-S4 supported this idea: “An important part of being an engineer is if you’re creating something new, it has to change what’s already happened before. There’s no point in doing something that’s already been done so the creativity is an important part of that because otherwise you’re just sort of reinventing the wheel and there’s no point in doing that” (ME-S4). On the other hand, ME instructors’ emphasis was on the expectation of a full functional end product.

What was observed in PDE design units was encouragement for creativity in developing the projects. However, in ME tutorials students didn’t talk about their designs unless they had an issue or were specifically asked about it. In PDE studios students were regularly getting feedback from their instructors about their design project, whereas in ME tutorials students were concerned about the test and exam questions. As one interviewee put it: “In PDE studio the creativity is a must, you have to have it, otherwise it’s a pretty poor effort. Whereas in ME if you design a pretty basic gear-box that functions really well we still get really good marks and they’ll be impressed. But in PDE if you design something that functions, works really well, but if it’s not creative and not interesting, that doesn’t meet the expectations” (PDE-S2). When the interviewees were asked if the instructors encouraged creative thinking they again did a comparison: “ME lecturer says make it well. When you compare PDE lecturers, they always give you tips how PDE graduate works, how they think and they definitely encourage you to be unique” (PDE-S1). PDE-S2 asserted that s/he “didn’t really notice huge focus on creativity in ME. I don’t think it’s really encouraged. They don’t give a lot of guidance about creativity. In PDE, there’s a lot of encouragement from lecturers. They encourage you, even it functions, to may be improve the aesthetic, or may be the function work better, may be trying to look at it from another perspective. Even if you bring something good, there’s always ways of improving it in terms of creativity. We didn’t get that kind of guidance in ME” (PDE-S2).

PDE students, by having taken both design subjects in ME and PDE, were in the position of critically examining the differences in the approaches to creativity. Their feelings and thoughts about the distinction between ME and PDE instructors towards creativity and creative thinking supported all the findings derived from the observations.

It is apparent that, there is much more encouragement, promotion of creativity and guidance in PDE than in ME education.

4.2.5 Design Problems

Giving open-ended questions to engineering students is a common way to increase creativity, because they allow multiple possible solutions and the possibility of generating alternative ideas (Daly et al., 2014). Many subjects in engineering curricula teach analysis, using well-defined problems. Whereas, design problems are usually ill-defined and the step-by-step way of learning does not help. The biggest difficulty in engineering design subjects is learning a new approach (Zemke & Zemke, 2013). The UC indicated that one challenge in the ME design process was "breaking the habit of some students who are accustomed to do things in sequential steps". ME-I1 outlined that "in engineering in general we have structured work solving problems […] There's always a route to follow. An understanding of rules that traditionally wouldn't apply to a specific problem but to see beyond the traditional way of doing things, that's creativity". It was clear that ME students are accustomed to solving problems in steps and are somewhat uncomfortable with ill-defined problems, which results in a lack of experience in the creative process. This finding is in agreement with de Vere et al.'s (2010b, p.38) findings which show that "engineers are typically engaged in pragmatic problem-solving, where cost-effective and known solutions are developed through sequential convergence on solution". Dick (1985) says that engineering students' abilities for defining and solving open-ended problems are not very developed.

When we look at the design problems of both courses, it can accurately be said that PDE design problems are more open-ended than the design problems of ME. To give an overview, the problems presented for this particular study are as follows: MD offered 4 different problems, 3 of which demanded an increased effort and a longer time to solve than the usual length of the semester. Therefore, most of the students preferred the simple, least open-ended problem, due to less commitment and requirements. The most preferred problem in this case was a "gear-box" for MD, and a "Solar-boat" for MSD.

To give an overview, PDE-I1 clarified the difference between ME and PDE design problems: "The problems that PDE students tackle are not necessarily well-defined problems. Whereas I see a lot of engineering projects students show me, there's a set of criteria an agreed end point like a gear-box where they know the outcome. In PDE design process, we don't know what the outcome will be till we get there. It's different than other engineering that it's a bit less defined" (PDE-I1). The distinction that PDE-I1 indicated can clearly be seen in the project definitions in the unit outline; ME design projects were "to develop a solar powered boat" (MEE40002 –UO-2014) or "to design and build from laser cut acrylic sheet and rod a gear-box" (MEE30003-UO-2015). As one student put it: "You've got a very good idea of what the final product will look like in ME, it's a gear-box. Whereas in PDE you start with a broader brief. There's a lot more time spent building the idea and then developing that idea (PDE-S2)".

For the PDE equivalent students were tasked to design "The Microheat Project" (DPD30001 Project Brief Microheat). The primary objective of the project is to find new applications for the Microheat water heating technology within an allocated scenario and to prove that the application is viable; an open-ended problem. Another problem was "to design a group of cutlery for a defined demographic" (DPD20002 Project Brief Spork).

Even though the gear-box was a design problem, students find it more narrow-ended which inhibits creativity. One response from a ME student was as follows: "There is no creativity in the gear-boxes – It's more figuring out the maths, rather than envisaging how to make it. It's just making it work" (ME-S7). Whereas, the nature of the design problems in PDE were more open-ended when compared to ME design problems. PDE students were interviewed to make comparisons between the type of design problems they experienced in the ME and PDE contexts. First, the reason for choosing the gear-box project in MD was asked of students, as there were other options to choose from. The general response was that it was the easiest project in MD and they "didn't want a high workload" (PDE-S1). PDE-S2 explained that he wanted to put a lot more focus on his design subjects: "Gear-box would allow me to spend more time on my PDE design subjects" (PDE-S2). This shows that PDE students prefer to spend more time for their PDE design projects by choosing the project in ME that required less of a workload.

Another essential difference between design problems is that in PDE humans are involved. In the design of a gear-box or a Solar-boat, no human variables are relevant, whereas cutlery is designed directly for human use. These results suggest that PDE design problems are more human related. de Vere (2013) also highlights the different "user approach" of engineering programs: "It is apparent that both require consideration of the user, whether that user is the end customer, an assembly worker in a manufacturing plant or an on-site product installation technician" (de Vere, 2013, p. 362).

It was observed that ME students struggled with the ambiguous nature of design problems. Instructors gave examples on how to work through the issues associated with projects with constraints and encouraged the students to learn how to answer ill-defined problems to change their mindsets. However, students found themselves underprepared to tackle such a project. Because, until now, they had been accustomed to knowing the answers or to know how to solve the problems as a result of traditional education in which they were exposed to closed-ended problems. But when presented with such an open-ended question they initially struggled. These are the classic challenges that a first year PDE student experiences.

While PDE students are experiencing a design process every semester, and even a few times in one semester, ME students have only two chances, in the 3rd and 4th years of their engineering course. ME-S1 reported that they face an open-ended design problem only twice throughout their university education. The first one was in MD, although the problem — designing a gear-box — had more limitations and was not as open-ended as the Solar-boat project in MSD. PDE students start their 3rd year with previously gained knowledge and experience of the design process. They are aware of the expectations of the creative process and without the need to be reminded they focus on generating alternatives and developing concepts. On the other hand, ME students have no previous design experience and they are new to the creative process. Therefore, it takes time for them to adapt to a different thinking technique.

This is not necessarily the student's fault, as throughout their ME degree students have not been taught the essential design skills to successfully work through ill-defined open-ended problems. Dutson et al. (1997) explain that open-ended design projects are developed to improve the design skills of engineering students. They "allow divergent thinking" (Wulf, 2000) and they might have more than one acceptable solution (Runco, 2007). Ghosh (1993) supports giving engineering students open-ended problems, because for an open-ended question a creative approach is essential (de Bono, 1996). As Cross (2008) put forth “people who prefer the certainty of structured, well-defined problems will never appreciate the delight of being a designer”. These arguments support the idea of exposing students to more design process. For future projects in this area, students should be provided more open-ended design questions and they should be guided and motivated to develop their own way of solving problems by working through the design process. This approach is believed to help students nurture their creative thinking skills in design process.

However, just introducing open-ended questions without any planning about desired results is not enough to improve creativity (Daly et al., 2014). For ME students need to understand the design process from early in their degree and to practise many types of design problems. PDE students have many shared units in first year with ID, teaching them the necessary design skills required to develop an innovative idea. It’s not just the skills that are learnt, it’s the design process and the way in which these skills can be applied to any given problem.

4.2.5.1 Problem Framing

Problem framing is worth mentioning because MSDs Design Unit not only includes designing, but also writing frames for design problems was given the most time and practice during the lectures. The unit started with problem defining and framing exercises. Instructors gave critiques about writing a good frame. Without researching, or starting the design process – by just using words, students were expected to frame the given problems such as “design a coffee cup that can’t be spilled” or “design a 15 cm long cane for the blind that can fit into one’s pocket when not in use”. These problems were not given to be solved, but just to write frames for. However, in PDE classes framing was an iterative process that begins with designing and you might need to frame the problem again and again. Students come up with such an idea that they might change the initial frame by sheer virtue of going through the various iterative steps of the design process.

When the difficulties of the unit were asked of student participants, almost half of them mentioned that they all have struggled in the beginning on how to write a frame. But within time, they understood the idea and found it very beneficial (ME-S1) in terms of creative thinking (ME-S2). One survey question was asking how the “problem framing” process affected creativity. One ME instructor responded that “the empirical evidence suggests that framing is an important reasoning step that comes before the problem-solving and complements it”. The other ME instructor stated that the answer was unknown and still under research, but thought that the frame was affected by creativity, rather than the reverse. ME-S2 claimed that “the process of framing supports creative thinking” by allowing students to think laterally. ME-I1 sees that the framing of the problem might lead to better generation of ideas. Previous studies also confirm that framing is associated with creativity. Dorst and Cross (2011, p. 431) specify “defining and framing the design problem is a key aspect of creativity”. Cross and Clayburn-Cross (1998) show how framing the problem in a new and productive way gives rise to innovative ideas by studying expert designer behaviours.

PDE students, even if they didn’t know how to solve the problem technically, first defined the idea or concept, then they figured out how to solve it. They reframed the problem while solving it. However, the ME student approach was different. Students didn’t take any risks if they didn’t know how to solve the problem. One of the given problems for students in class was “how to extinguish the fire” for a group discussion. ME-I5 said that some students came up with the idea of preventing the fire at the first place. But some students rejected that as the question was not asking how to prevent but how to extinguish it. It was somewhat surprising to notice that even though ME students practice framing a lot, some were hesitant about reframing the given design problem. It might be because they practise framing and designing separately with different design problems. Another example was given by the UC that during designing the Solar-boats, s/he admired one group’s approach which was to win the competition by preventing the solar source of the other boats. This is a way of reframing the problem by generating alternative solutions to a given problem. Framing is a very important milestone in a design process, which helps you reframe and solve the problem through creative thinking.

This study argues that framing could be combined with the design project. If students are allowed to reframe the given design problem during idea generation process, this encourages students to experience a fruitful creative process by generating alternative solutions during problem-solving before developing their chosen idea and finalising it.

4.2.6 Sketching as a Means of Communication

The result of the survey question (Figure 4.8) shows that most of the students think freehand drawing skill is highly important. However, ME students' sketching quality was poor when compared to PDE students, which was identified by the ME instructors who teach both disciplines. It was also stated by Kuys and de Vere (2010). It was observed that the lack of freehand drawing skills for ME students blocked their ability to visually communicate ideas on paper, forcing them to explain ideas verbally. In the design process, ME students used more words, whereas PDE students used more sketching. The ability to sketch ideas on paper was a much more effective tool to communicate the entire artefact they were designing.

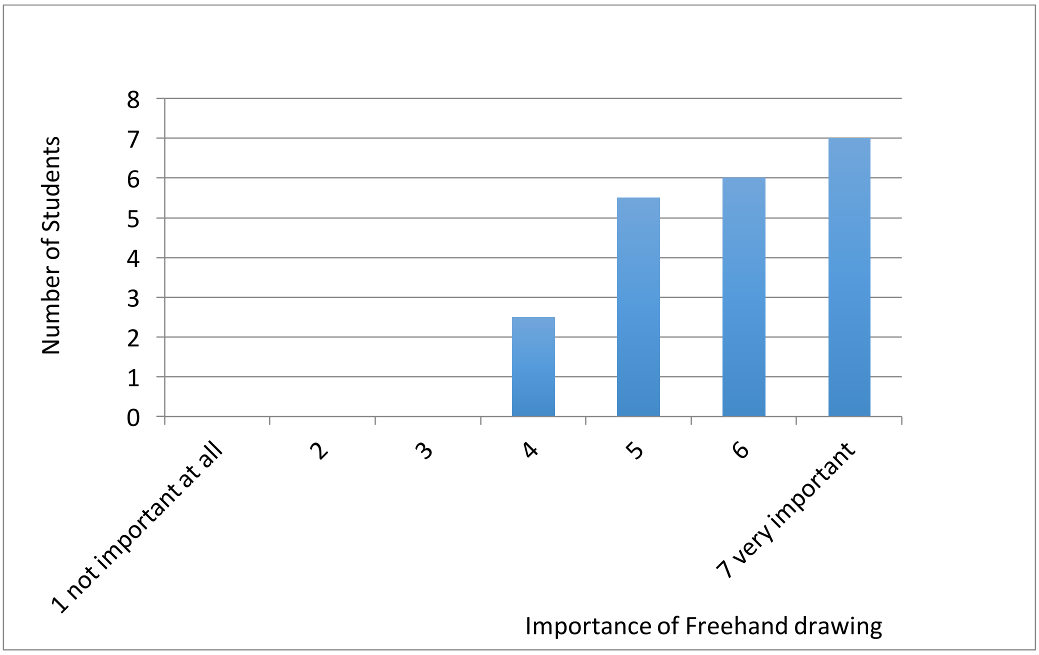

Figure 4.8 Importance of freehand drawing

The reason of their poor sketching techniques results from two aspects. First of all, it was observed that ME students were not expected to do good quality sketches and they were not going to be graded for this effort. What was surprising and noticeable was the habit of ME students carrying a lined A4 size well-known traditional notebook and PDE students carrying an A3 size sketchbook. ME students did not use a sketchbook or carry any special kind of sketching pens or pencils that were drawing friendly like PDE students. So it was observed that they could not get in the mood that would trigger their attitude towards drawing. The other reason was the structure of the teams. It did not allow ME students to put much effort into hand drawings like PDE students. Data shows that if there was a PDE student in the team, s/he is the one who did all the hand sketching and the CAD drawings. Some of the ME students said they had learned how to use the CAD programs but they preferred not to do it, because they already had someone in their team from PDE who actually did the job. So this seems to be a block for them against showing any effort for sketching.

It was observed that three of the PDE students attended the PDE studio with A3 size sketches. Coming to design studio classes with a folio became a habit of PDE students. What was interesting though is that they did not maintain this habit when they went to ME tutorials. When they were asked why they behaved differently in different design subjects PDE-S2 admitted that he “didn’t approach the MD project really as a design project”. When the reason for that was asked s/he said “The unit wasn’t presented that way. There wasn’t enough guidance on how to approach the design problem, how to actually build it. They just said this is the project, read up on the chapter on the gears and then try to build a gear-box […] It didn’t really say go through this week doing this research. This week doing this development” (PDE-S2). This demonstrates the lack of guidance from the instructors, which will be explained later.

Another point worth mentioning is the difference between using hand drawings and CAD drawings during idea generation. Most ME students preferred starting their design work with CAD software, whereas PDE students initially drew by hand and then did CAD modelling after the design was somewhat resolved on paper. PDE-I1 indicated that although hand drawing was “still open to interpretation”, CAD drawings meant the “idea is finalised and completed”. ME-I1 supported this idea by saying he observed that students become fixated to their ideas after they made their CAD drawings and do not want to change anything in the design. Also, CAD hinders creativity as designs tend to be developed according to the CAD skills of the operator (ME-I1).

PDE students were also inclined towards the use of CAD. However, there was a constant encouragement and expectation from PDE instructors about initially focusing on hand drawing and sketching. Because “it’s vital for communication” (PDE-I1) both with clients and other designers. PDE-I1 says “Sketching has a huge impact because if a student can’t get the idea out of their head onto a piece of paper then it’s very hard for someone else to understand it […]. You need to work things out a little bit before you jump on the CAD. I think students are very confident with CAD. They think if it works on the computer it will work in the real world" (PDE-I1). On the other hand, doing quick hand sketching might be a more practical basis on which to discuss ideas. ME-I4 agreed that "everything starts with sketching, it is quick and simple". PDE instructors regularly warned students about not starting the CAD drawings before they solve everything first. Otherwise they would be fixated on the initial CAD modelled idea (PDE-I3).

The author is not suggesting that all engineering students need to be able to sketch to a high quality, but is rather suggesting that sketching skills need to be developed to a basic level to give engineering students the means to visually communicate ideas in an understandable manner; currently this is rarely done for ME students. It must be impressed on students to use CAD modelling at the last stage.

PDE-I3 declares that "ideally the more hands-on you get, the quicker you learn". Previously mentioned survey results (Figure 4.3) show that there are more Kinaesthetic learners than others, which means a large number of students learn by doing. This supports the idea of 'design and build'.

4.2.6.1 Keeping a Folio

There were a range of responses to the question about the instructors expecting drawings from students during the design process and how they encouraged students to draw. ME instructors agreed that they expect drawings and sketches from the students. They encouraged students "to include drawings in the report" (ME-I1), because the rubric says that the students have to have different drawings and sketches (ME-I1, ME-I3). However, the results did not indicate that the drawings were expected, as only a few of the reports included drawings.

The UC mentioned that s/he reminded the students how important drawing and sketching were in finding better solutions during class. But s/he (UC) admitted that in the end only a quarter of the students did proper sketching, and these were actually PDE students or "the students who really want to learn about the process" (ME-I3). Another idea was that "ME students get basic drawing skills" as "drawing helps the visual and kinaesthetic learners a lot" (UC). However, "instructors don't have time to develop these skills in students" (UC).

When instructors were asked about the advantages that keeping a folio would bring in terms of creativity, ME-I3 commented that they could see the design process and the project development from the sketches. PDE-I2 says that "it's a demonstration of the progression of skills […] It's also important for the students just to understand they've gained significant skills along the way […] You can always go back and see the other ideas. It helps you explore different things easier […] Creativity will only happen after so much amount of work. If you limit them, students will not do it. But if you push them they come up with really good stuff" (PDE-I2). PDE rubrics always indicate the number of quality pages full of sketches to be submitted (Appendix XX and XXI).

Like PDE students, ME students should also be expected to develop a range of alternative design ideas through the act of sketching for their projects. This would encourage them to use a sketchbook for the entire semester and postpone the use of CAD until the design has been created on paper first. It is believed that this act alone will help foster creativity, as certain barriers hindering creativity would have been removed. This can be done by turning the expectations into requirements and putting them in the rubric and unit outline as deliverables and by constantly encouraging and reminding students.

4.2.7 Design Process

The design process is an iterative process and takes time as it occurs in various stages. Even though both discipline's instructors believe the importance of the process in a design class, their approach to the situation is different. PDE instructors emphasise the quality of the creative process rather than the quality of the final product. They encourage students to develop different ideas, always asking, "what's new here" (PDE-I1), and promote creative thinking. However, in ME the focus seems to be purely on the final product. These interpretations are validated from the student responses that ME cares more about the final product, rather than the process of getting to the final product. Previous research supports this finding by indicating that the primary focus of engineering is an artefact, whereas design education focuses on the students in helping them understand and experience the process of realising an artefact (Sheppard & Jenison, 1996).

The PDE student, who also took MD unit claims, “In PDE, the end product is really important, but how you get there is just as important […] In ME definitely the product outcome is the most important” (PDE-S1). S/he made an interesting distinction: “In ME they want you to make a functional product, and then chuck in creativity afterwards, whereas in PDE studio they want us to incorporate it from the start […] In PDE we spend a lot more time through ideation and the earlier stages where you develop the idea. Whereas in ME, we come up with an idea that we’re satisfied with and then we refine just that idea and try to make it as functional as possible” (PDE-S1). Therefore, they preferred not to spend more time in an ME unit to be creative. It can clearly be seen from the perspective of PDE students who experienced both units that there is quite a difference in the creativity approaches of the two disciplines. PDE students see creativity as an ‘extra’ aspect and not really integrated into ME units, however creativity is a part of the PDE units.

When the expected major outcome of the ME design project was requested, whether it was the design process or the product, all ME instructors agreed that the process was the most important part. However, they reported that the assessment was not designed for that. ME-I1 argues that design problems are a good way for the students to be creative, but when a design component is just about the end product but not the process it’s a big challenge. “Because creativity does not come in the product, it comes in the process when you are solving the problems” (ME-I1). Accordingly, students care only about the product, because for students it’s all about where the marks are allocated. “If the emphasis is on the final product outcome, that’s what they care about the most” (ME-I1).

PDE has a different approach. PDE-I1 expresses her/his thoughts about creativity: “In a learning context, I am a real fan of process […] Creativity is about taking a risk that is harder in educational contexts […] I tend to favour my process and the student’s ability to try lots of variables, lots of solutions to the problem. I would grade that higher than necessarily the final outcome even if the functionally needs refinement. Creativity is essential for problem-solving but also for risk taking […] I tend to favour looking at assessment as a process. If someone works through the process thoroughly, that ranks more heavily on the final grading than the actual outcome” (PDE-I1). PDE-I2 also states that they assess more the process: “The end product doesn’t necessarily need to be as innovative or creative as we would have liked, however, learning the process is more important and that’s what we mark on”.

Risk taking is one of the important necessities for creativity, even though risk-taking is considered a personality trait. It might be hard to encourage risk taking, but it should not be discouraged by educators (Kazerounian & Foley, 2007). “Creativity requires risk-taking and there is no innovation without risk taking” (Sahlberg, 2009, p. 343). PDI-I1 supports this view by indicating that “creativity is risk taking”. Even both course instructors seem to encourage risk taking. ME students admit they don’t take any risks, because they think if they fail, there will be no mark for it. It is apparent that the current situation in ME doesn’t allow students to take risks to be creative, which is illustrated in Figure 4.9.

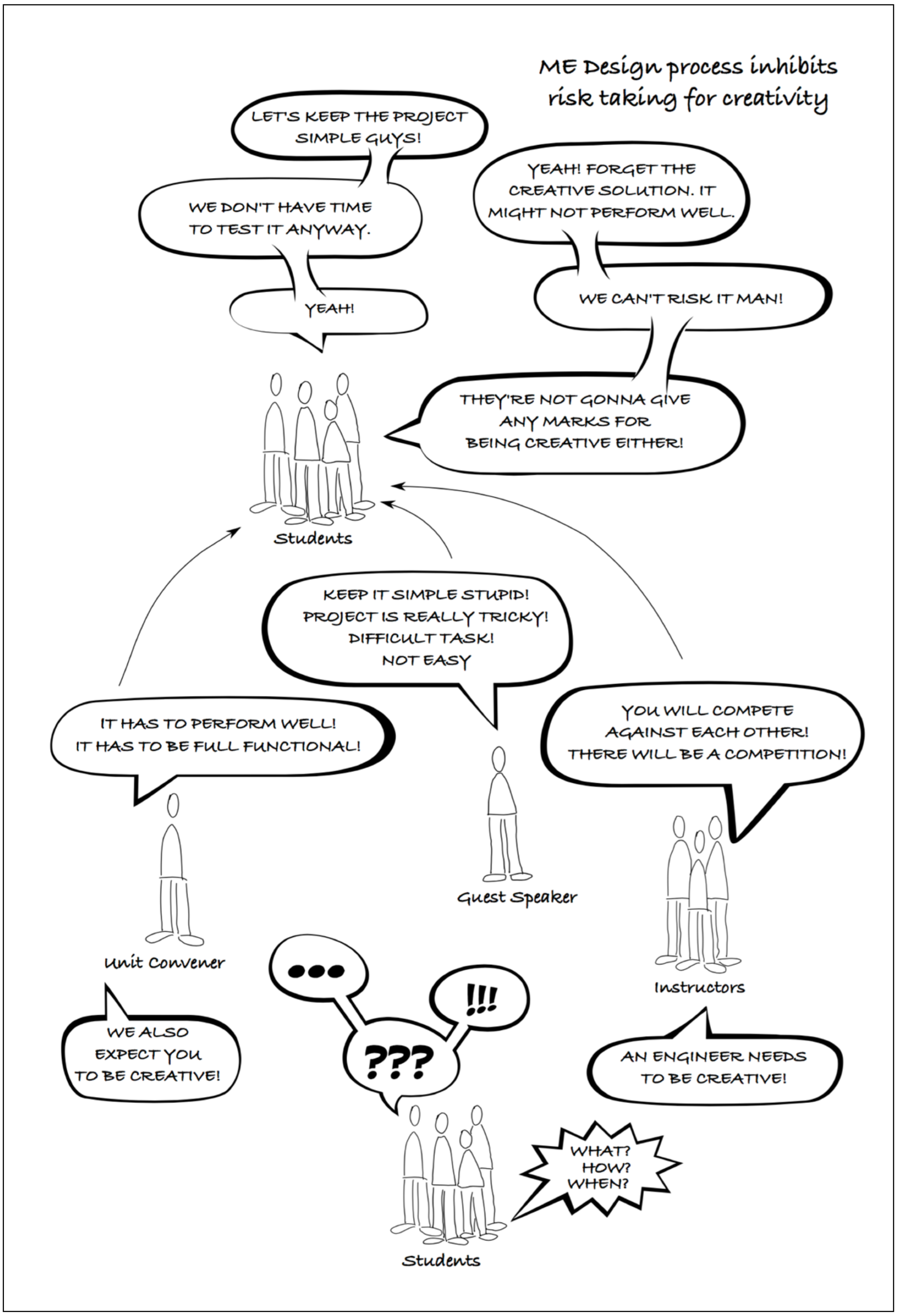

Figure 4.9 Risk taking in ME design units

4.2.7.1 *Tutorial Hours*

It was observed that ME students were not expected to develop their design projects in tutorials. No idea generation phase or development process took place during tutorial hours. Rather the students used them to ask their technical questions, to do framing exercises or to get prepared for the exam. The idea generation process was done somewhere outside the class and the students came up with their final concepts with no initial input from the instructors. Instructors just focused on the students' final decisions, which are often fixated at an early stage with limited development. Some students were not even aware that these tutorials were supposed to be for the design progress. When asked why they did not use the tutorial hours to work on design, one of the interesting responses was that they assumed they needed to do the design works in their own time (ME-S1). Students specified that they preferred to develop their design project when they regularly met as a team outside the class hours. ME-S2 talked about their ideas with the tutor a little bit, but admitted that they did not sit down and discuss the idea in-depth. ME-S2 told that they were asked by their instructor in the beginning of the semester how they want to spend the tutorials; by learning more on the subject or focusing more on the projects. ME-S2 said that the students preferred the first one and completed the design work outside. ME-I1 clarified that "the students do not prefer to use tutorial hours for design process" and added "when students show us their works towards the end you may not be able to change anything" (ME-I1). So this situation was apparently not preferred by the ME instructors either. ME-I1's suggestion of expecting students to regularly show and tell about their works might be helpful for witnessing the design process, "because the way it is now is not working" (ME-I1). S/he admitted that they had not tried discussing the process before (ME-I1). However, ME-I3 pointed to a limitation: "for 6 groups, 1 tutor is not enough in a two hour-class". On the other hand, PDE studios had two instructors, generally one from ID and one from PDE backgrounds, split into two groups. Students always had the chance to talk to both to gain a wider perspective.

The overall design process in PDE was different. PDE-I3 illustrated their creative process: "We take the students through a range of processes throughout the various studios, starting with a very basic studio introduction to design, talking about the methodology, the steps required to take creative ideas to execution […] But in terms of creativity we use various tools to try and get them to think about how to come up with new ideas through various methodologies really". PDE instructors continuously reminded students about the future deliverables. They clearly indicated what was expected from the students at every step. PDE students were specifically given what needed to be done for the next class such as "brainstorm 10 ideas as thumbnails on week 2" or "pin-up presentations with 3 ideas on week 3". Conversely, in an ME context the unit outline (MEE40002-UO-2014) only says "show your plan and literature to the tutor" or "show alternatives to tutor". In tutorials, ME instructors asked students "if" they want to show their designs, however in PDE it was expected from students to show their designs every time. PDE-I1 clarified that they did not want anybody to fall behind. That's why they had these milestones; and they kept track of each students' development. However, ME students were expected to manage their own time. It is an interesting paradox though, that students were able to show their creative abilities under strict and more prescriptive circumstances.

Lack of time management affected students' problem-solving processes. ME students admitted that they went with the easiest solution first to build a working product. Then some groups kept the design and some tried to make it more creative: "We just basically picked a design we thought would be easiest to translate into real life […] We mostly just build the design. We looked up a few articles and the literature review and then from there we had various designs which we narrowed down to one; built it; tested it; it worked so we kept it that design" (ME-S6). It clearly shows that the time constraint of a 12-weeks semester influenced the choice of the simplest design to implement. Therefore, instructors must be there to help students in managing their time effectively to experience a more fruitful design process.

When ME students were asked if there were elements missing from MSD tutorials that would improve their creative thinking skills, responses were focused on experiencing a more guided design process: Some of the suggestions were doing "more hands on experience", more "guidelines to promote creative thinking and creative activities", "more examples of design", "mentoring from experienced designers", "more problem exploration", "more brainstorming exercises or projects" and more "creative exercises" (2014-MSD-SWS). These findings show us that the unit content could be reorganised by including more creative practices in a better and more detailed schedule.

As a result, both PDE and ME instructors think that the design process is as important as the product. PDE instructors witness and assess students' design process during problem-solving by presentations, pin-up sessions or regular checks. Whereas, ME instructors can only witness and assess the design process at the end of the semester, in a written format submitted within reports. Figure 4.10 and 4.11 show the differences between ME and PDE design process approaches.

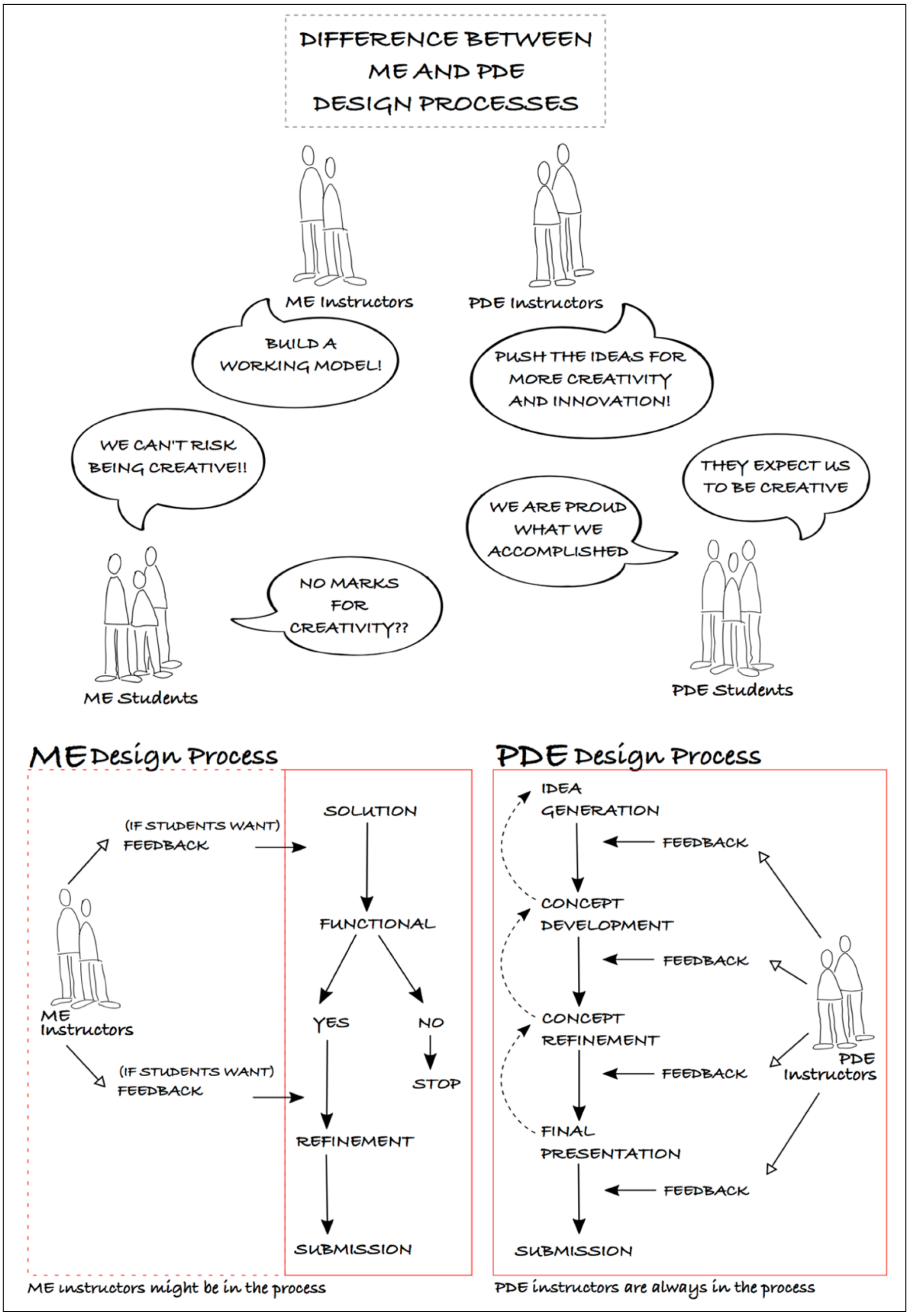

Figure 4.10 Difference between the ME and PDE design processes

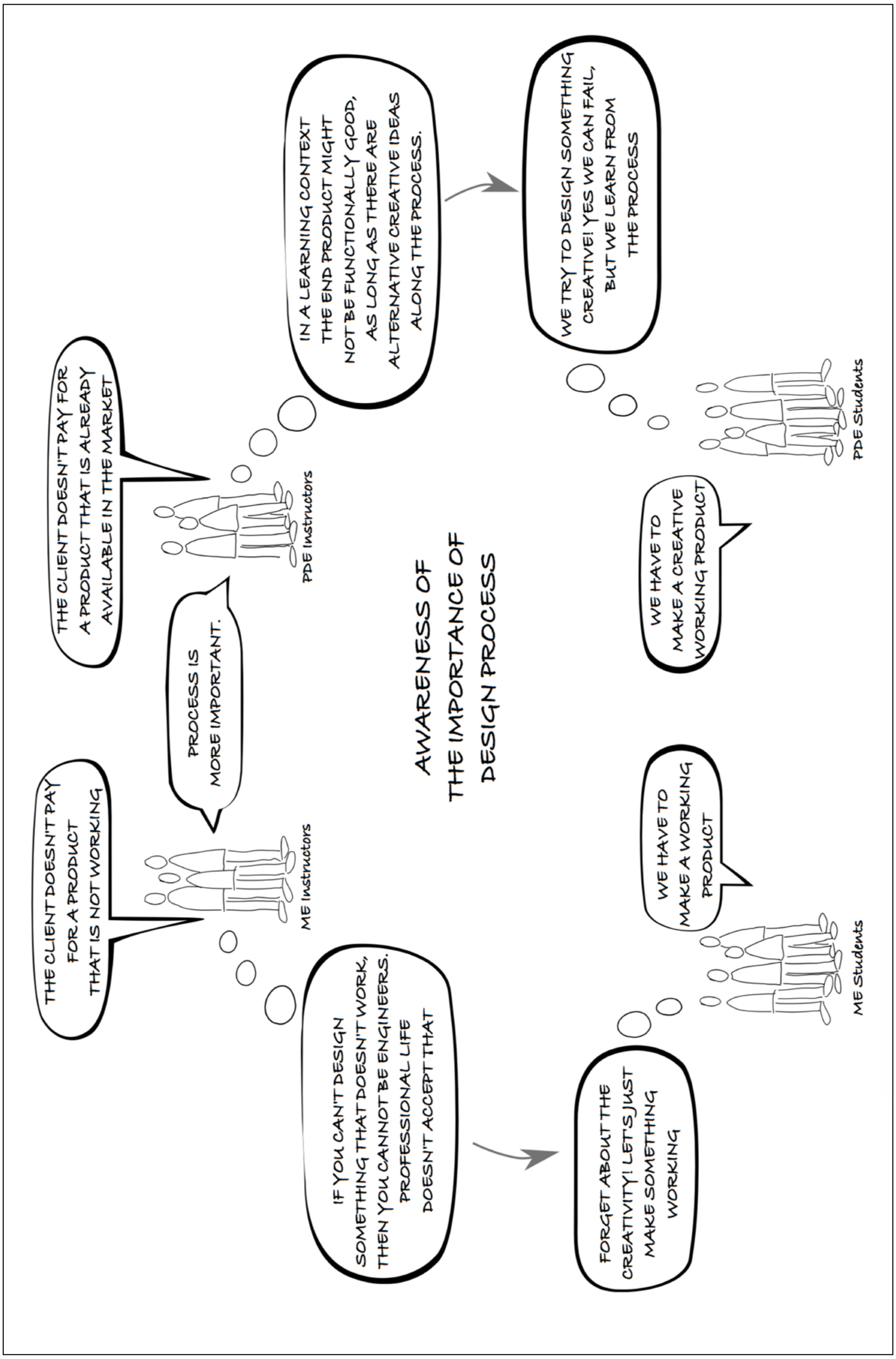

Figure 4.11 Awareness of the importance of the design process

4.2.8 Performance Mindset vs. Creativity

A number of ME instructors shared their concerns and supported what students indicated. ME-I1 declared that some student work was not creative but won the competition and the ones that were creative actually lost it, because of performance issues. ME-I1 self-criticised their way of teaching that if they care and give marks only to performance, then all the students focus on performance. This shows the ever-complicated compromise between a product's function/performance and its level of creativity. Obviously, the product's performance is integral to the success of the outcome, however, the level of creativity should not be compromised and always considered.

The competitive nature of the problem made students think that only the final product is important for assessment. This result could have been triggered by the UC's declaration that "as a designer all your designs need to be implemented in reality, and they need to work". This approach was putting a lot of pressure on students that the end product had to work whether it was creative or not. Also, the previous research based on protocol studies supports the idea that ME students, when compared to design students, focus more on the solution and the functionality of the final product rather than the process (Gero & Jiang, 2014; Lande & Oplinger, 2014; Mann & Tekmen-Araci, 2014). On the other hand, when students were presenting their works, PDE instructors wanted to hear the whole story; where students got their inspiration, what the initial idea was, and how it evolved and developed. PDE instructors would like to see all the students' drawings from the beginning, to witness the whole creative process. That is why students were expected to present a folio in the end, showing the design process.

Although both course instructors of the two disciplines think in a similar way, students think differently. In an ME context, the idea of 'the product has to work in the end' (ME-I1) brings many constraints and some students prefer to play it safe by not taking any risks. If you come up with a working solution, you meet the expectations, however, PDE is not satisfied with just a working solution but goes beyond it. During one of the classes, a PDE instructor explained to the students that "it doesn't matter in an educational context, but you cannot say your client that you didn't do the calculations correctly and the product is not working". Therefore, PDE students were also expected to calculate the efficiency of their projects at early stages of the design process. In short, PDE students are aware of the fact that creativity happens during the design process and they're less afraid of failing (in the context of a working solution and not in the context of the unit assessment), which allows them to think more creatively. On the other hand, ME students put so much emphasis on making the product perform well they tend to forget about creativity and just focus on the performance of the product, which unfortunately misses the benefits of the creative process.

4.2.9 Guidance Through the Design Process

There is a difference between the approach of ME and PDE instructors during the design process. PDE students got feedback from their instructors about all kind of aspects, from technical issues to drawing quality, from user interface to presentation skills, and especially when deciding between alternative solutions. However, in ME, students were expected to decide almost everything by themselves. ME students did not get guidance as much as PDE students throughout their design process. ME students were not expected to show their progress to their instructors, whereas PDE students were required to come to class with sketches of alternative ideas to discuss in class. Then they regularly presented their works and got critiques from their instructors and their peers to help develop their ideas. Instructors were aware of the whole design process, how it started and evolved during the semester and how it was finalised in the end. These regular checks helped PDE students in their decision-making and prevented any issues around early fixation. Although ME instructors encouraged students not to stick on one solution but to look for different configurations, they did not ask if students had other alternatives or not during the critique sessions. The idea generation phase was very quick and students focused directly on solving the details of the project.

In PDE studio units, it was observed that PDE instructors spent a long time to discuss all details of the works with each team. They were always interested in student works throughout the whole design process and not just on the final solution. During the desk critique sessions, it was observed that PDE students developed a bonding with their instructors, which was not very common in ME tutorials. PDE-S1 indicated that instructors "make an effort to give you feedback each week, you don't want to disappoint them in the end" (PDE-S1). This particular comment shows how student motivation towards creativity can be affected by instructor' approaches.

When the advantages of regular checks of student works was asked of PDE-I3, s/he noted that if the students didn't get feedback along the design process and went too far in the wrong direction it would be too late to change: "So the idea is to give feedback in that they understand the process and what they are doing, and at the same time to make sure they progress in a logical fashion" (PDE-I3). PDE-I1 stated that it is "about managing the timeline of the 12-week semester".

When students were asked if they showed their designs to get feedback, PDE-S2 says that they did it "every week in PDE, but there wasn't enough time for it in ME tutorials". A PDE student put forward the difference of ME design units: "Minimal instructor support in reference to design as compared to other design units" (2015-MD-SWS). When one student complained about the lack of guidance in ME and the difficulty of choosing the best solution in between the alternatives they created, the response from the UC was straight: "Just choose something". PDE-S1 criticizes MD, saying that "there isn't much guidance about creativity" and the instructors "have the curriculum in front of them, saying everything needed by Week 12, and that's it. However, in PDE they want to check up on you to see the improvements every week" (PDE-S1). When it was asked to students how they preferred to be treated in ME tutorials, PDE-S1 said that they preferred to be checked regularly: "In PDE we've always been given guidance and encouragement about how to push the design further […] It not only keeps you up to date, it also pushes you to make a good product" (PDE-S1). It was apparent that PDE students gained an approach towards developing their ideas based on the feedbacks they got from their instructors. But interestingly, they admitted that they did not apply the same approach in ME design units to develop their projects; "probably because we were the minority and they had their own approach" (PDE-S2). It is obvious that PDE students do not behave in an ME context how they were trained in PDE. They prefer to behave according to the context they are in. As Baer and Kaufman (2005) declare, improving creativity in a subject does not necessarily help in improving creativity in another.

Another point worth mentioning is the motivation of the instructors. It was observed that ME-I3 was very excited at the end of the semester when students from his tutorial won the final competition. It apparently motivated the instructor as an educator. Therefore, not only students' but also the instructors' motivation is an essential factor, as it informs the students' motivation. Figure 4.12 shows the factors affecting student motivation during design units. de Bono (1993) links motivation directly to creativity. He thinks creativity is a great motivator as it makes people more interested in the subject, gives hope, makes life more fun and provides an appropriate framework for teamwork.

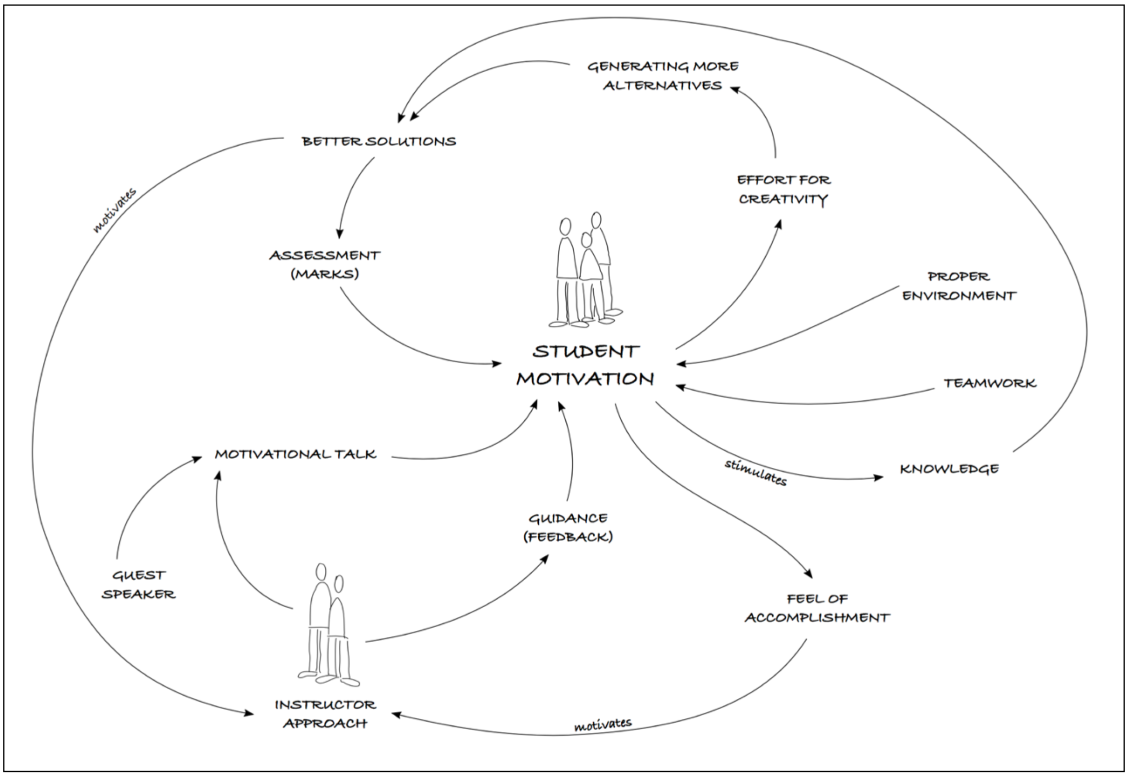

Figure 4.12 Factors effecting student motivation

ME-I1 indicated "if you want to teach creativity to people who have never been creative like novice designers, they might end up lost in the end". Taken together, these results suggest that there might be an association between increasing the instructor guidance in class, students' own time management and motivation towards the subject, which directly affects the creative process.

4.2.10 Presentations

One of the significant differences between ME and PDE design units was the student presentations. They were regular events in PDE, however, students were not expected to present anything in ME, not even when they finished their design project at the end of the semester.

The presentation sessions started as early as the second week of the semester in PDE. Some presentations took form as informal sessions where all the students hung their drawings on classroom walls and discussed them one by one. After these pin-up sessions students got many critiques from everyone and spent time on the areas which needed to be developed. PDE instructors explained how the presentations would be done, how many minutes the students were expected to talk and what aspects of the projects needed to be explained; in short they guided the students on how to structure their presentations. Students were always informed about what kind of details they needed to show in their presentations. During the formal presentations, each team usually talked about 15-20 minutes. The instructors and the other students asked questions and gave feedback on which project alternatives had more potential or which one was more convenient for development. Depending on the feedback they got, students were expected to come up with better, qualified and more developed ideas. All students listened to each other's presentations. Instructors were motivational, emphasizing the positive sides and gently mentioning the negative sides in guiding the development. When there were no presentations PDE students still brought their A3 size drawings to class and talked about them with their instructors giving feedback.

In addition to these observations the PDE instructors were questioned about the value of giving presentations in terms of creativity. PDE-I3 believed that "it's a skill that good engineers, good designers have to be able to explain and articulate their design" (PDE-I2). PDE-I3 thought that "it's a chance to explain what they have done [...] Presentations help in their professional life. You will always have to stand up and justify your thoughts [...] All kinds of engineers need it [...] Having the confidence to back your own design and have a logical justification why you went through these steps to end up with this end result, that can be transferred to any industry". These responses do not show a direct link between creativity and presentations, however, they help students to be more aware of their solution choices and to manage their time, aspects which are implicitly related to the creative process.

In order to understand the issue from the student perspective, they were asked about the effect of giving presentations. PDE-S1 stated that "in PDE we put almost 12 weeks of work into this. And we want to show it to the class, to show off what we can do. Whereas, in ME, OK, I've done the work, I've hit the criteria, I'm done [...] With the gear-box there's no sense of accomplishment; there's a paper saying what it has to do, so we satisfied the piece of paper. On the other one (in PDE), I've satisfied what they've asked us to do, but we've also tested ourselves in making a product we're proud of". An interesting point is the similarity of the ME instructor's experience back in their educational life: "We were given a design problem, and told design something to fulfil the brief. If we won, we got full marks, it was graded down to who showed up with something that met the brief" (ME-I4).

PDE-S2 also supported PDE-S1's view that "there's a sense of accomplishment with the presentations in PDE. Because you spend so much time on it and it showcases your work in a really nice way. When there's the presentation, you got it forever. The earlier presentations kept us up to date. You don't wanna be the person who hasn't done the work. There's always a sense of competition in PDE. You want to be the best group in the class". It's an interesting finding that, even though the assessment of design works in ME were arranged as a competition, students felt themselves in a more competitive environment in PDE that excites and motivates them. This was done by having presentations in an environment where everybody sees each other's work.

Comparing the two results, it is believed that presentations could be encouraged more in ME design subjects, where everybody can present their works and see other design solutions, which in the long run help students in their professional life. It would give students more of a sense of accomplishment and motivation toward the unit, which in the end affects the creative process. Because motivation is an important aspect in fostering creativity in education the students' sense of self-accomplishment needs to be strengthened to motivate their development of creativity (Vukasinovic et al., 2011).

4.2.11 Creativity Tools

Literature lists many creativity tools to use in PBL, such as brainstorming, mind maps, random words, analogy, TRIZ, divergent thinking, lateral thinking, SCAMPER, brain writing, the 6-3-5 Method and many more. As the aim of this research is to enhance creativity in engineering education it was important to understand if any type of creativity tools were taught, promoted or used within the classroom environment.

It was observed that some creativity and rationality tools were introduced to ME students in MSD but only around 30 minutes was spent on this. The ME instructors again mentioned creativity tools during the tutorials, but they did not go beyond explaining a few basic tips about these tools. Instead of practising the creativity tools during class hours, students were expected to apply them to their idea generation phase when the teams came together without the supervision and advise of an instructor. However, without learning and practising these tools correctly, students would not know how and when to use them. ME students were expected to write a report to reflect their creative process. It was observed that rather than applying the tools to generate ideas ME students were more occupied with describing the tools and writing about them for a report.

However, in PDE studios, both in 2nd and 3rd year, students came with a basic knowledge of creativity tools that were taught in their first year education. PDE-I2 explains that they use various tools to try and get students to think about how to come up with new ideas. PDE-I1 admitted that they “give creativity thinking processes, mind maps, word associations, rapid visualisations at first year”, so that the students had the ability to apply them to their projects with the direction of their instructors. PDE students have this embedded in all ‘studio’ activities throughout their degree, whereas ME students do not. PDE-I1 advised that “lots of design thinking methods and tools can be applied to the product development process. Sometimes students need to see how that tool furthers the project along the process”.

Survey results show that the most used creativity medium by ME students was “brainstorming”. ME-S1 mentioned that they need to practise more creativity tools and suggested giving students homework each week encouraging them to use different tools. S/he thinks these home works would be motivational if they will be marked, so that each week they would have the chance to develop that skill (ME-S1). When PDE instructors were asked about the creativity tools that students generally use, PDE-I2 indicated that they also do a lot of “brainstorming”. However, there was a difference. Instructors asked the students usually at the start of each topic to actually set aside time to do that methodical brainstorming technique, which they were introduced to in the first year (PDE-I3). PDE-I3 added that they “just refresh their memories in later years”.

This shows that PDE instructors allocate time for doing proper creativity sessions in class, rather than expecting the students to do it by themselves.

SCAMPER was introduced in PDE 2nd year studio classes to help in developing students' concepts. Student comments after applying the tool are as follows: "It provided us to think outside the box", "we came up with ideas that we didn't think before", "the tool helped us to think from very different perspectives". Instead of just giving students the SCAMPER keywords, I, both as the lecturer and the researcher, walked among the students and helped them to correlate the keywords with their products. All teams found it handy, useful and efficient and came up with many ideas, which in the end helped them to develop their final design ideas. However, it was observed that ME students did not get much out of it, like PDE students did. One reason could be that PDE students were marked for their effort when they applied this tool in class as it related to their design process.

As a result, it can be said that the use of creativity tools was expected in the ME unit, but the way of promoting it was insufficient. Students first need to understand how to use these tools properly. ME-I1 compared learning creative thinking processes to learning how to swim: "If they do not know swimming, they may freeze. First they need to test it before jumping in it".

It is believed that similarly to PDE students, ME students should be introduced and encouraged to apply basic creativity tools in tutorials, to develop their creative output. Instructors for these subjects should also be given professional development training on how to facilitate different versions of idea generation sessions. Creative activities should be repeated to develop habits amongst staff and students, which ultimately affect the creative design process. This also accords with previous studies, which show that the facilitator is as important as using some basic thinking tools (Zhou, 2012c). Facilitators create the atmosphere that is appropriate for idea generation. They also select the most appropriate techniques for the participants and the context (Baillie & Walker, 1998). They are responsible in teaching how to recognize and remove creativity blockers (Liu & Schonwetter, 2004). In order to achieve this, educator training programs must be developed to improve the capacity in the teaching of creativity (Panthalookaran, 2011a).

4.2.12 Rewarding Creativity

It is argued that creativity must be encouraged and appropriately rewarded for more student involvement and motivation about creative thinking. If educators encourage creativity, the students will be more enthusiastic about attempting it (Kazerounian & Foley, 2007).

The assessment of an MD unit is based on the following: Examination 40%, Tests 10%, Design performance 20 % and Project report 30%. The performance of the gear-box is based on a formula, depending on the mass lifted, the height and the weight lifted, the time taken and the axial length of the gear-box. It also depends on the lowest and the highest performance achieved within the unit. Each team needs to submit a report explaining the design with suitable drawings, the key design decisions, documenting the modelling and calculations and reviews the performance of the design.

Creativity appears only as a criterion in the report, but not directly using the word "creativity". It is assessed for the design process under the categories such as concept generation, concept selection or concept analysis. Even though ME instructors indicated that they were expecting alternative creative solutions from students, they admitted that it was not a criterion for the final design product. They all agree that there was not much about product creativity in the marking criteria. One of the instructors said, "creativity was supposed to be part of it", but they did not actually think about how to assess it (ME-I1), and "it was not the main assessment criteria" (UC). The instructors expected students to be creative but they "failed to capture the way in which this is assessed" (ME-I1). "The criteria of marking must reflect what we want them to do, if it is creativity, let's give marks to creativity". Then they would get more benefit from the tutorials (ME-I1).

It was observed in one of the ME tutorials that the students were explaining a creative solution to a problem that they came up with to their instructors. But in the end, they decided not to do this project because it was complex. When the students were asked why they did not go for that particular solution they said there was no need for extra effort as they were sure they were not going to be awarded for being creative or innovative. One of the students also said they "know that if their boat does not win the competition, they will not be awarded for coming up with a creative idea". They said that only functionality was expected from them and there would not be any marks for creativity. According to the survey results (Figure 4.13) less than half of the ME students thought that creativity was a criterion for the design work.

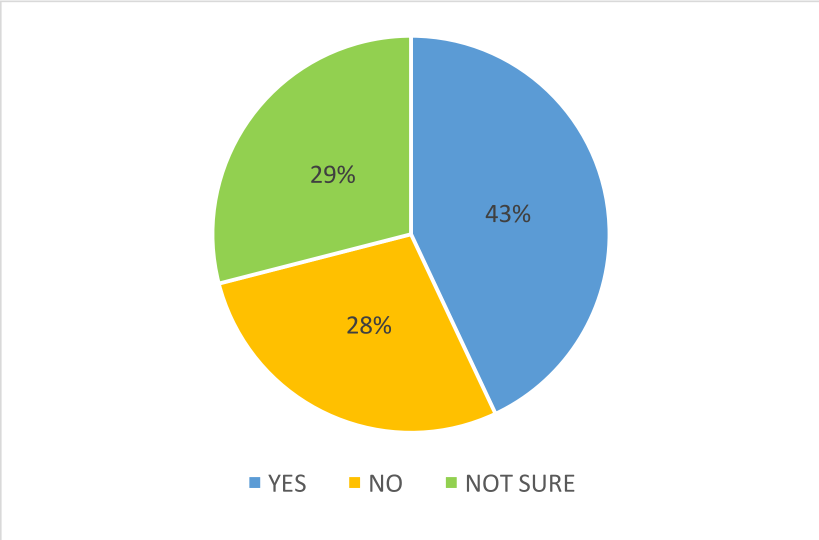

Figure 4.13 Student responses to “Is creativity an assessment criterion?”

When ME instructors were asked what would happen if they increased the percentage of marks for the design project, their responses were likeminded. They all agreed that the problem was not the percentage of marks for design in the course, but what elements within design the marks were given to. ME-I1 highlighted the part that needs improvement: “The mark was not given to creativity but to reliability that the product must work […] Even if you increase it to 50%, it will still be reliability, not creativity […] Now we don’t have marks for creativity, that’s why nobody goes for creativity” (ME-I1). ME-I3 suggested balancing the assessment and allocating some marks to creativity as well as reliability as students were spending more time dealing with the design part.

The assessment of the PDE unit was divided as follows: Scoping and Ideation 20%, Detail Design 25%, Verification and Engineering Documentation Deliverables 40% and Presentation Pitch Deliverables 15% (DPD30001-UO-2015). However, this is a real project for a real client and was run as a competition that was judged on the final student pitch to company staff. Microheat assessed the work against the following criteria: What’s new and innovative in the proposal, the quality of engineering and manufacturing in the proposal, the aesthetics of the proposal, and the presentation and potential market for the product.

The PDE instructors all agreed that creativity was expected in the design projects: “It’s a definite assessment criterion and it is structured on different sorts of levels” (PDE-I2). “It is necessary. It is more like innovation, which works backwards to creativity […] Students need to have a variety of ideas […] You need to be creative enough to think lots of different ideas” (PDE-I3). Instructors were asked how they encouraged students to push their ideas for more creativity. PDE-I1 said s/he initially assessed the folio by looking at the number of different ideas the students have. Because “thinking and coming up with a broad range of ideas” is an expression of creativity (PDE-I1). PDE-I3 said that during the consultation sessions they gave “that little push to going in the correct direction, which is encouragement” for the students.

The results of this study suggest that if the ME assessment method was modified to make creativity a significant part of the design process and the product, it might have affected the overall design quality in terms of creativity. It is suggested that an assessment against creativity would enhance the level of innovation in the course, including in the ME design units.

The focus on the exam is another factor in ME attention to the design process. It is observed that ME students, unlike PDE students, tend to focus more on the exam, rather than on the design project. Students mostly used tutorial hours to prepare for the exam. ME-I1 supported this observation by indicating that when the exam was counting for 40% of marks in the course the attention was there. “If you don’t tell students its worth something, they don’t put effort in”. The UC explained that the reason for having an exam is that it is “one piece of assessment that is individual and under controlled circumstances. That is the only situation that you know it’s this person’s performance”. On the other hand, when PDE instructors were asked why there was not an exam for PDE design units, PDE-I1 answered that s/he can’t think of what kind of exam to have: “It’s very hard with a design process to have an exam. Oral presentation is like an exam. It is about explaining your product outcome, how you verify, how it sits compared to the competitor, how it may be sustainable, how you used your calculations to verify. I never thought of making an exam” (PDE-I1). However, s/he added that “the idea of having an exam at the end, which is quantifiable is very attractive to test the knowledge, but a project can test their knowledge too" (PDE-I1). PDE-I2 saw the thought of having exams as "interesting" and could not accept that an examination process, coming up with a right and wrong answer, was necessarily going to assist in getting people to create, innovate, and explore new things: "Coming up with new solutions don't come necessarily in an exam environment where there is a limited time frame. You need time to come up with new concepts and they need to evolve over time" (PDE-I2). S/he added that "historically design studio has always had this sort of process of doing projects" without exams (PDE-I2). Similarly, the UC stated that engineering design subjects had always had exams. This shows that how structuring their units depends on what the disciplines had been done previously.

Observing that ME students spent a lot of time in preparing for the exam that was worth 40% and sacrificing time spent on their design projects for this, alternative methods should be considered to assess student knowledge of creative thinking in a design unit. Even though Lim, Lee, and Lee (2014) declare that a mark driven environment does not support students for creativity, and more flexible ways of assessment are needed, the research in this study shows that students are motivated by marks.

4.2.12.1 Self/Peer Assessment

It was observed that PDE instructors gave importance to peer evaluations during presentations. When there was a presentation session in a PDE unit all the students in that class were expected to listen to their peers' presentations and give feedback. A self and peer review scheme, taken from Stanford Design School, (Appendix XXIII) was distributed to students by their instructor. PDE-I1 thinks the success of peer assessment depends on the team dynamics. If students are willing to comment, "There's a lot learning in peer review process" (PDE-I1). PDE-I2 pointed to the importance of students' understanding of their skill sets and their ideas amongst their peers: "We're always doing pin-ups and then analysing the ideas that they've got. We're trying to encourage students to comment on them professionally, give some feedback to the students, whether they think the idea is warranted, whether there are any other ideas that stems from their presentation for the student to progress their design or progress their idea" (PDE-I2).

This process has many advantages: First, when students had the chance to listen to others' presentations, they notice different points than the instructors and give feedback to their peers. Secondly, students not only learn from their own failures and successes during the design process but also from observing others. In addition, they could practise evaluating the works, which allows them to evaluate their own works. Mitchell (1998) confirms this finding by emphasising peer and self-assessment in engineering classes for developing students' evaluation skills. Further work is required to establish this in ME.

4.2.12.2 Competitions

As mentioned earlier, the main projects conducted in PDE and ME have a competitive element to them. ME design projects — e.g. Solar-boats mentioned previously— would compete against each other on the final day. PDE design projects — Microheat — would be evaluated by the Microheat team to choose the best solution.

Students were asked about the effect of competition on their creative process. All students found that competition was a good idea, enjoyable, motivational and was actually increasing creativity. Other advantages were seeing others' works and learning from them (ME-S1). ME-S2, by highlighting all the effort everyone had put into it, claimed that "there will not be that much effort if it was not a competition".

When the instructors were asked about the assessment of the design projects according to the competition, they had similar ideas. ME-I1 explained the advantages and disadvantages of the competition: "It is good for engineering students, because it's a main drive for the students besides marks. Competition is a motivation engagement with assessment. But some students might feel they are not capable and they might give up. Another disadvantage is that their marks depend on not only to their performance but also to the others' performance" (ME-I1). The UC supports using this method because it eliminates the students' thoughts like "the teacher doesn't like me" when they got bad marks. When there is a competition, there will be no argument of like or dislike. A competition gives students independent feedback so that they cannot blame bias (UC). "As long as there is a challenge, creativity occurs" (UC). ME-I3 thought having a competition is good and it affected motivation positively, but there were things missing, like choosing the best design. Because s/he (ME-I3) believed that the idea behind the design was also important, the assessment should not be just based on the best performance. Apparently, the competitive nature of the design projects has an effect on student motivation and creativity; however, just depending on performance as a competition criterion, is not enough in promoting creativity; design projects should also consider creativity in the ME design projects.

4.2.13 Teamwork

The strong link between creativity in engineering education and team working skills has been identified by many researchers (Pappas, 2002; Zemke & Zemke, 2013; Burton & White, 1999; Stouffer et al., 2004; Cropley, 2015). Teamwork also stimulates motivation through the feeling of belonging and the taking on of responsibilities towards the team (Vukasinovic et al., 2011).

Both MSD and MD units required teamwork in design projects. ME design projects needed to be done by a team of 4, which was difficult to establish in a short period with the given restrictions. The students were expected to decide on their team members in the first week and report their names to their instructors. The most significant challenge in the beginning of the semester was to form project teams, which had strict rules such as having at least one international student, at least one PDE student, at least two ME students and two local students (MEE40002-UO-2015). The little number of PDE and international students made it hard to establish the teams in a week, because students did not know who was local or international and it took a long time to figure it out.

Student comments also supported the observation that this was a difficult challenge: “Groups need to be selected prior to the beginning of the semester. By the time a group is found, it is already week 3–4 and so much time is already wasted” (2015-MD-SFS). ME-I3 also highlighted the stressful and time-consuming team formation phase in the beginning of the semester: “It took away most of the design process time”. S/he (ME-I3) believed that it needs to be solved on Week 1. Students, who were able to establish a team from the first week were luckier than the others. It was also observed that some students, who could not find a team to join, felt isolated and left the tutorials early. However, in PDE, team working was easier: project teams needed to be made up of 2 students. Additionally, all students knew each other in the PDE class because of the lower number of 25-30 students compared to 180 ME students.

When it was asked of the instructors if they think teamwork encourages creativity they all agreed, but had some concerns. ME-I1 explained the advantages and disadvantages of teamwork: It is good in terms of witnessing different life experiences and the collaboration between ME students who are better in mechanisms and PDE students who are better in sketching (ME-I1). ME-I3 gave the real-life example that people are working as a team in an office, which is why team working is good for students' future life. But there are some negative effects as well. One student can think that his/her idea is the best and if s/he has a dominant voice in the group others might just give up. The groups having dominant students failed. (ME-I1; ME-I3). Students agreed that it was good to have team members from different ages, gender and disciplines (ME-S1). ME-S2 highlighted the importance of the team; "a lot of motivation comes when you work as a team", but also mentioned that some group members did not do much at all, which caused work load issues. Students described the benefits of working in a team: "Exchanging ideas and brainstorming", "learning from others", "splitting the work load" and "creating more options and ideas" were the main reasons for team working (2014-MSD-SWS).

Working in a team is a good way of learning from others and a practice for professional life. It is apparent that establishing the teams earlier in the semester is a significant issue to solve, which negatively effects the time allocated for the idea generation process. Related to this issue, time management during the design process is shown in Figure 4.14. In short, the challenge in ME design units was team building rather than team working.

4.3 CONCLUSION

This study provided a detailed insight into issues associated with embedding creativity in the engineering curriculum through in-class observations, surveys and interviews. This was done to critically examine the creativity issues in the ME curriculum by focusing on engineering design units. The aim of this investigation is to identify the creativity problems in ME design subjects through observations, analysing the relevant literature and leveraging design pedagogy in PDE. The goal of this research is to determine if there exists a possibility for improving creative thinking among ME students by referencing the PDE approach to studying design, which has not been investigated by prior researchers.

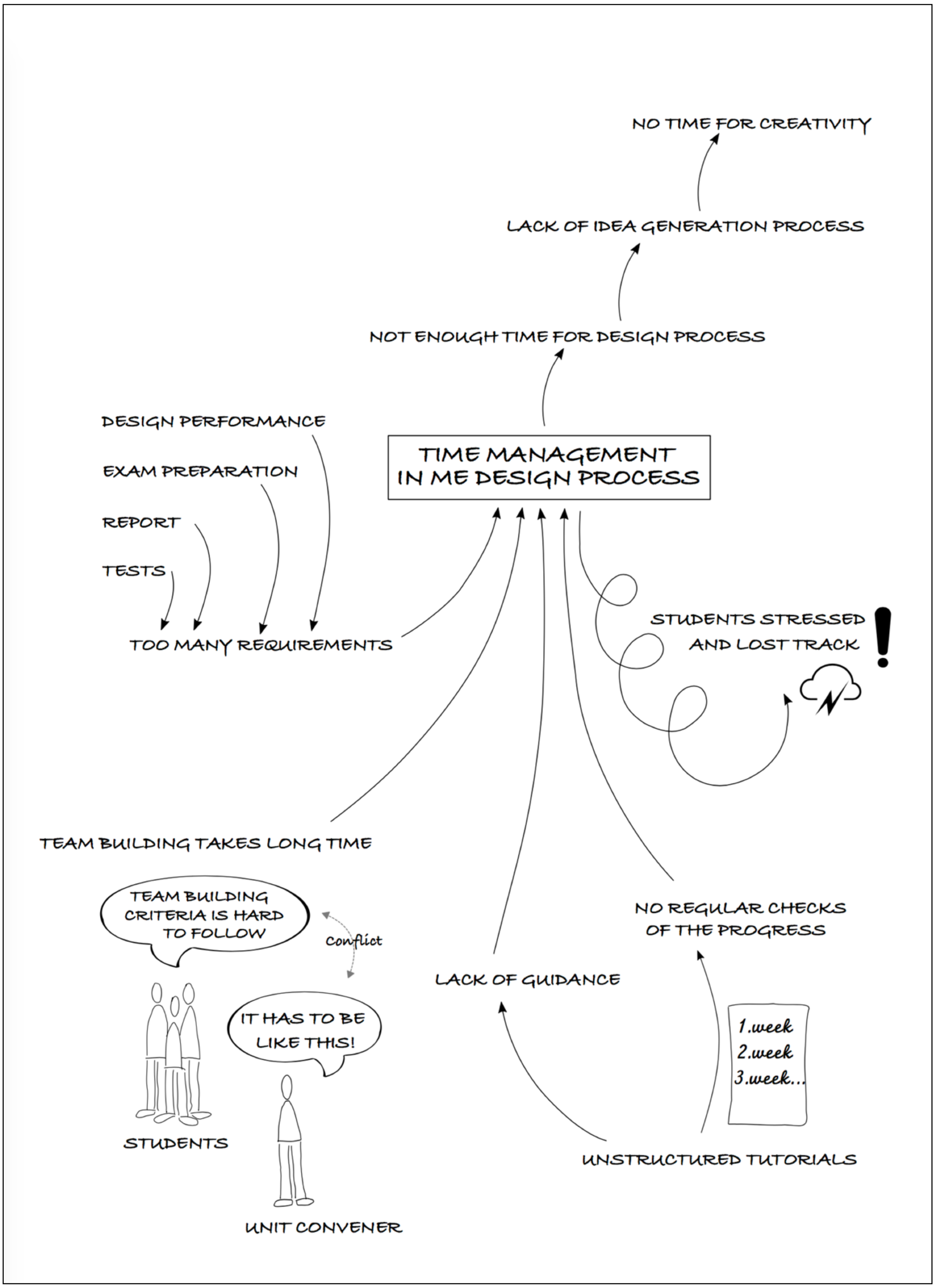

Figure 4.14 Time management in ME design process

Initially, the study outlines the differences between PDE and ME design processes, which gives clues about the instructor approach, the expectations from students and the structure of the units. These findings are believed to help in embedding creativity in engineering education. It is apparent that even though creativity is valued it seems to be viewed as an 'extra' aspect and is not really integrated into ME units, whereas it is an integral part of the PDE education process. In order to enhance creativity in ME design units, these following issues must be addressed:

- There must be more encouragement, promotion of creativity and guidance in ME education. ME instructors do not value group discussions enough, do not value sketching, peer assessments, presentations, use of creativity tools or giving feedbacks to students. It is argued that PDE instructors, when compared to ME instructors, encourage more creative solutions and push their students for more creative thinking, because they value creativity more than ME instructors value creativity. It is believed that similar to PDE, ME students should be introduced and encouraged to apply basic creativity tools in tutorials to develop their creative output, they should be encouraged to have more group discussions in class and should be expected to do presentations for getting feedback from their peers and instructors. The unit content could be reorganised by including more creative practices in a better and more detailed schedule.

- Students have time management issues in ME design units because of an inadequate team forming process and they are focusing too much on the final exam, which negatively affects time allocated for developing the creative process. When considering that ME students experience a design process for the first time in their educational life, it is suggested that they need some guidance in their time management. The author believes that ME instructors should encourage more project development in class and expect to put more input in the early stages of a project, which should enhance the quality of the creative process. This all depends on a better organised design process and good time management. This can be achieved by regular checks and by expecting students to regularly present their works.

- It is argued that assessments of creativity would enhance the level of innovation of each project. This study argues that assessing not only the performance but also the level of creativity of the design projects would increase students' creative thinking. The expectation of a fully functional end product should also include an expectation of a creative process and solution.

- A more appropriately configured design studio can be provided for ME tutorials, which would allow a proper seating plan for group discussions.

- ME students should be exposed to more open-ended problems that encourage creative solutions. A design subject each semester would better increase student's creative abilities throughout their degree.

A number of issues in ME design units in terms of creativity were identified, all of which will be addressed in Action Research (Chapter Five). Harnessing information gained from this study and converting this information into a creativity agenda for engineering students will help do this. This research argues for the need of a holistic approach to creativity in engineering education with the ultimate aim of fostering creativity among engineering students and helping them nurture their creative thinking skills throughout the design process.

Figure 4.15 shows the creativity issues identified in ME design education. Figure 4.16 shows the things that are observed to have positive effects on creativity and creative thinking in PDE design units, which could be transferred to ME. The reader should keep in mind that all of these factors were not implemented in ME design units in Action Research. There were many limitations, which will be explained in detail in the following chapters. These findings further support the idea of reconsidering ME design units in terms of the design process, the environment, instructor approach, time management, the assessment and expectations from the students for better creative teaching and learning. For the Action Research that follows this study, all these findings are discussed with the unit conveners about what to implement and how.

The next chapter, therefore, moves on to discuss the interventions that were conducted in the selected ME design units used for this study. All of the collected data in this chapter guided the Action Research conducted in the ME design units.

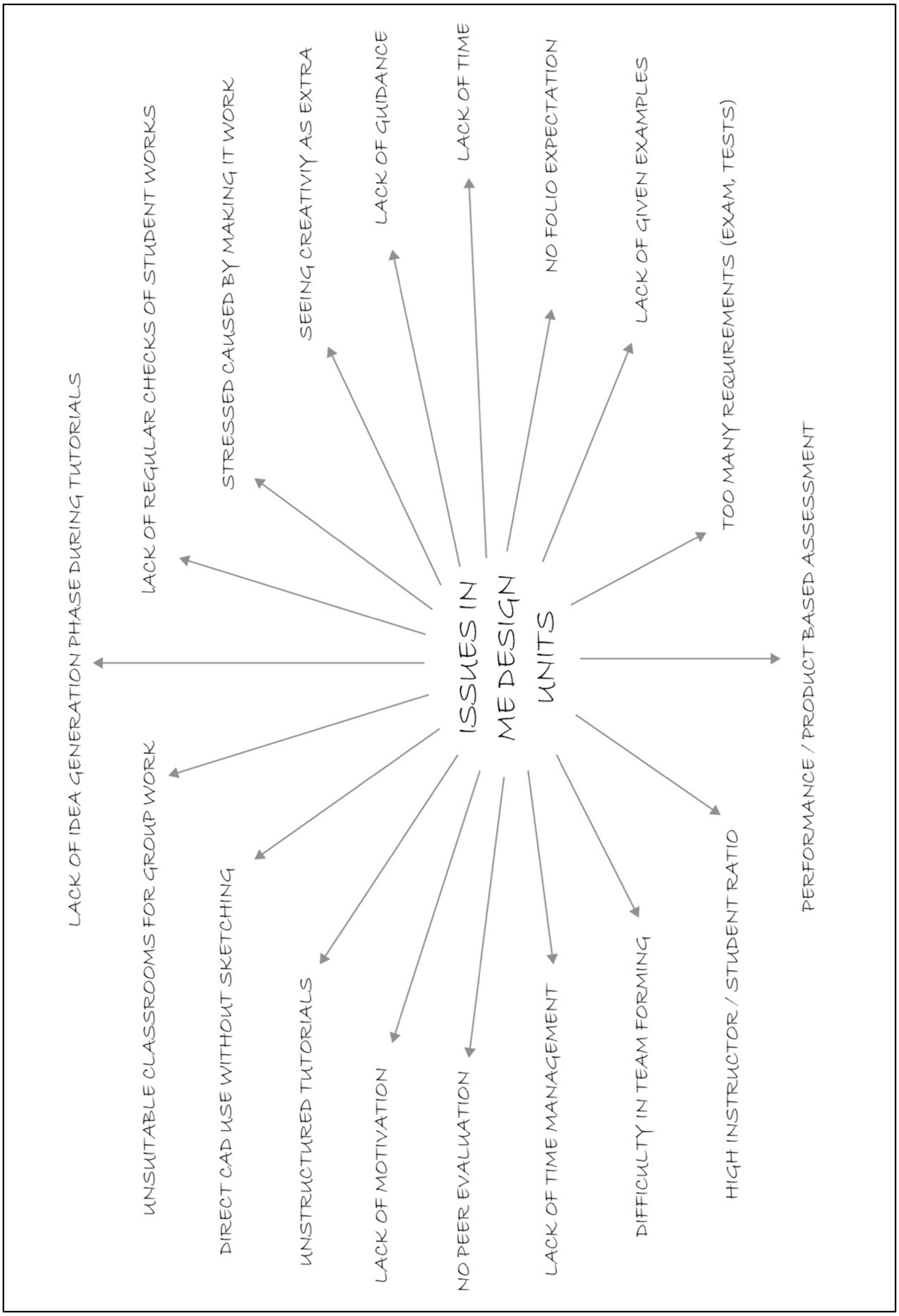

Figure 4.15 Creativity issues in ME design units

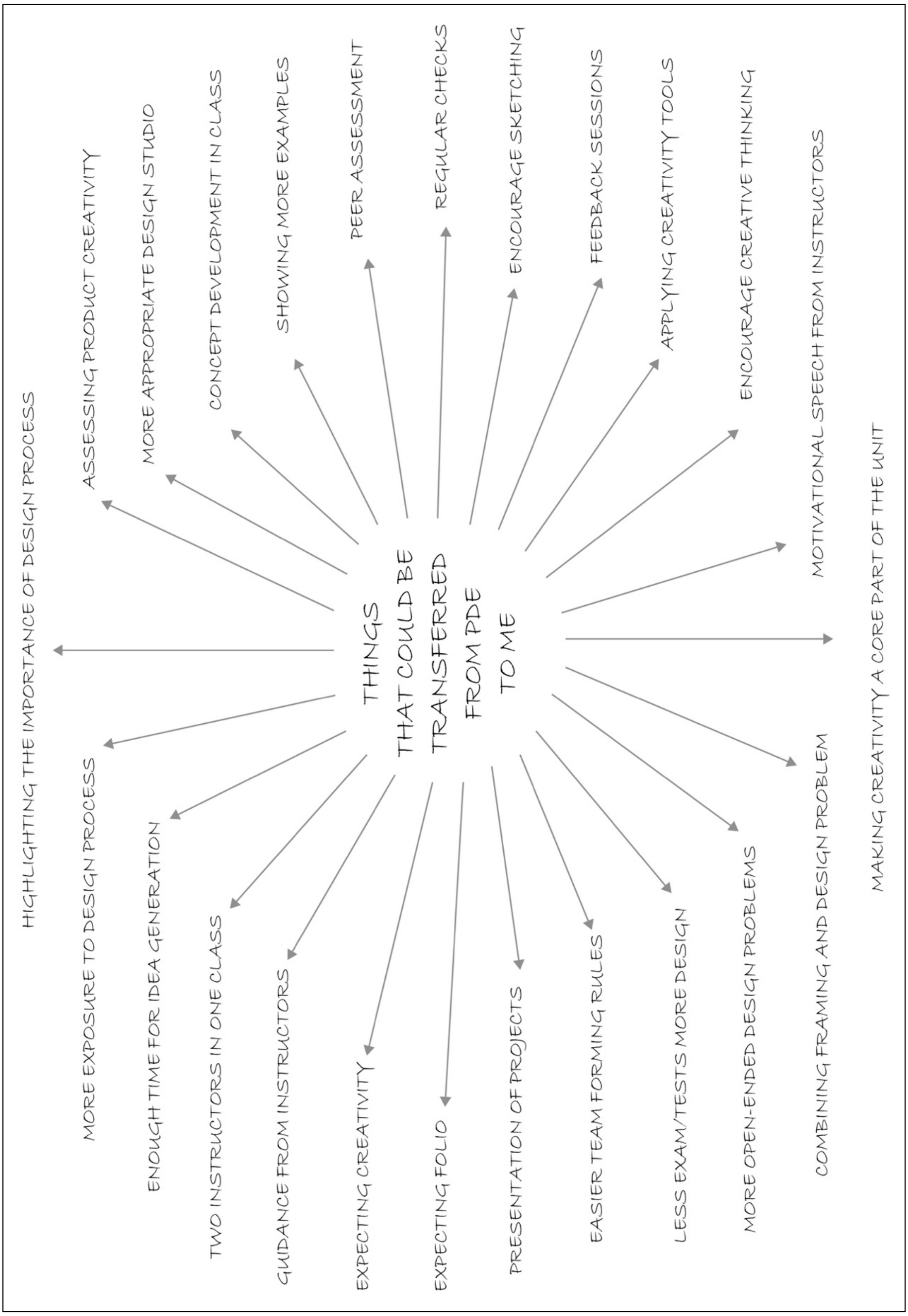

Figure 4.16 Things that could be transferred from PDE to ME

5 CHAPTER FIVE: ACTION RESEARCH IN MECHANICAL ENGINEERING DESIGN UNITS

5.1 INTRODUCTION

This chapter explains key aspects of the Action Research process examined in two Mechanical Engineering design units in two phases or semesters:

1. Machine Design (MD)
2. Mechanical Systems Design (MSD)

Chapter Five begins with the explanation of the study context. It then focuses on the phases of the Action Research by explaining the modifications implemented. It critically discusses the effects of all the implementations and concludes with the limitations of the study. It periodically reviews the data gained from the Action Research process, aiming to provide further insights for future studies.

During the Action Research, as much data as possible was collected from various sources. The process was continuously monitored during two semesters by a variety of data collection methods, like observations, surveys, interviews, and meetings.

The implementations during the Action Research involved two types of actions:

- General overarching implementations: These were planned to affect the whole semester and include changing the physical conditions of the classroom, giving suggestions to instructors about being motivational, or increasing guidance towards students. These actions were planned in accordance with the data gained in Chapter Four.

- Weekly implementations: These involved specific issues such as changing the assessment method of the design project, introducing a creativity tool or organising a session for students to present their works. These types of actions were designed and updated weekly according to collected and interpreted data.

When further issues relating to creativity were identified during the study, the weekly plans were modified and new plans were implemented. In the iterative cycle of Action Research, objectives and research questions shaped the choice of methodology, as the process was open to surprises and new opportunities. Therefore, the researcher could make critical modifications in the situations s/he works in such as classrooms or schools (Kemmis & McTaggart, 1988).

Overall, this chapter provides an important opportunity to advance the understanding of creativity teaching. It offers some important insights into the challenges of embedding and enhancing creativity in engineering education. Chapter Six follows this chapter with findings from the Action Research process.

5.1.1 Context of the Study

This chapter explains the process of Action Research conducted in two engineering units. Machine Design (MEE30003) is the first and Mechanical Systems Design (MEE40002) is the second of two engineering design units in Mechanical Engineering at Swinburne University of Technology. The observations were done through both semesters in 2015 and the interviews were carried out after assessment was completed. As Punch (2009, p. 147) indicated, the researcher facilitated, moderated, monitored and recorded group interaction.

The MD is in the first semester and the MSD unit is in the second semester in ME course. As the UC, the tutors and a majority of the students were the same in both units these two phases can be seen as a whole. Some of the interventions that could not be implemented in MD were attempted in MSD. The reader should view these two Action Research processes as a whole in this study.

The first Action Research process was mostly focused on teaching and introducing creativity to engineering students. Whereas, the second one focused more on the instructors. The second phase of Action Research was conducted without the author being a regular participant observer in the class. So, the communication with instructors and the unit convenors was increased by using different methods. The reason behind this was the findings from the first Action Research phase: If the aim is to encourage students to value creativity, it first needs to be valued by the engineering instructors.

Therefore, the researcher preferred to stay back, not to be present in the class and to try to support the instructors in their teaching instead of focusing on the students. Burns (1997) also highlights the benefit of the collaborative study of the researcher with the teachers in Action Research, as educators always seek the best method to do their job in the classroom.

In order to organise the collected data and suggest actions to implement, Soft System Methodology (SSM) (Checkland, 2000) was used. This helped to establish relationships between the issues that needed addressing and clarifying where to focus. The creativity issues that needed attention were identified in Chapter Four. However, it is not easy to change everything at the same time. Therefore, the actions that were related to each other were initially grouped and then linked with each other, depending on Checkland's (2000) suggestions. In the following steps of the SSM, the feasibility and applicability of all the planned and suggested interventions were discussed with the instructors and the UC. The details of the methods used in this process were explained in Chapter Three.

The instructors and the author for this study adapted Schon's (1983) concept of reflective practice. During the instructor meetings, all instructors reflected on their experiences. The author behaved both like a researcher and like a contributor.

5.2 ACTION RESEARCH IN MACHINE DESIGN

MD offered four different problems. The majority of the students chose the "gear-box" project. Student teams were to design and build a gear-box from laser cut acrylic. It needed to lift a certain weight, be a certain height and be powered by a standard electric motor. The second most popular problem was a project titled "great ball-handling contraption", which is described as "an ideal project for students who want more freedom and like the idea of something different" (MEE30003-UO-2015). Students were required to design a module to be displayed during the Open Day of the university to promote their discipline.

The Action Research process commenced before the term started and continued until the final marks were given. This process will be described in three phases, although there is not a distinct difference between them.

5.2.1 Action Phase 1: Recognising the Need to Change

This phase comprises the time before the semester started until the end of Week 1. Previous findings were turned into plans of actions. Their interrelations and their possible effects in embedding creativity were discussed with the UC. Figure 5.1 shows the interrelations of the suggested actions.

Table 5.1 shows the underlying reasons behind each action, which has been developed by considering Checkland's (2000) three questions while developing the model: "What to do?, How to do it?, Why do it?".

The suggested actions were shared with all the instructors in instructor meetings. The points that would help instructors to support their students in class during design process were indicated. These points were also provided as a file to instructors, titles as "Suggestions for tutors to do in ME tutorials" (Appendix XXIV).

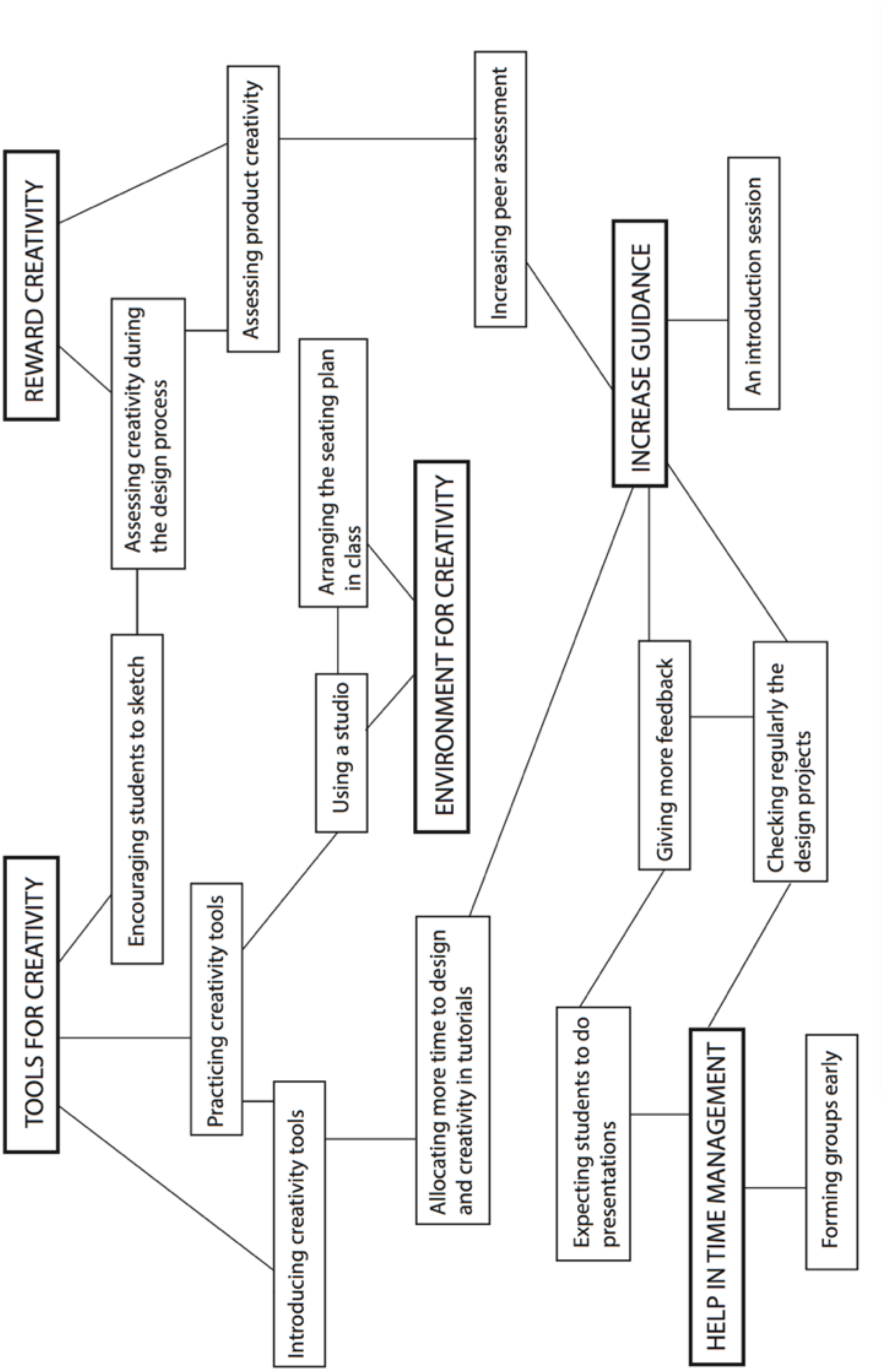

Figure 5.1 Interrelation of the suggested actions in MD

Table 5.1 Underlying reasons behind the suggested actions in Machine Design

What to do?	How to do?	Why to do?
MAIN FIELDS THAT NEED IMPROVEMENT	SUGGESTED ACTIONS	UNDERLYING REASONS OF THE SUGGESTED ACTIONS
TOOLS FOR CREATIVITY	Introducing creativity tools	to help idea generation and concept development process for better innovative ideas
	Practising creativity tools	to encourage students to practise the tools more than once for helping them to gain creative thinking skills for further use
	Encouraging students to sketch	to encourage sketching for communication during idea generation process and to develop freehand drawing skills
INCREASE GUIDANCE	An introduction session specific to design and creativity	to introduce and to have a discussion with the students about the process of engineering design and the role of creativity during that process
	Giving more feedback to students	to increase feedback/critique sessions on how to develop design works in terms of creativity and performance
	Checking regularly the design projects	to help students in their time management, to witness their design process and to make sure everyone is on the same track
	Allocating more time for design and creativity in tutorials	to encourage students to spend more time for generating alternatives and to make sure that students use the tutorial hours to develop their designs
	Increasing peer assessment	to encourage students evaluate others' designs and learn from each other
REWARD CREATIVITY	Assessing creativity during the design process	to highlight the importance of creativity during design process and to motivate students for creative thinking
	Assessing product creativity in addition to product performance	to motivate students for putting more effort on designing a creative product and to encourage them for risk taking for creative ideas
HELP IN TIME MANAGEMENT	Expecting students to do presentations in class	to give students more feedback (from peers and the instructor), to help them manage their time for the design process, to practice presentation skills and to learn from others
	Forming groups early	to increase the time for the initial idea generation process
ENVIRONMENT FOR CREATIVITY	Using a studio for the unit	to motivate students with a proper classroom which is designed for the act of designing
	Arranging the seating plan in class	to create a discussion environment by allowing students sit face-to-face for developing designs

5.2.1.1 Pre-action Phase

The UC started to send e-mails to students before the semester started, emphasising that design "is a new way of thinking, and it requires a different way of teaching" (E-mail 04/02/2015). Later, s/he explained that "The purpose of (saying) this was to make students feel like 'hang on it is not like the others'. Because they are used to go to the class with a notebook, ready to copy what has been told. The first aim was to open up their minds".

These e-mails were about the nature of the design problem, suggestions about how to be successful in the unit, the importance of getting into a team fast, and the benefits of using a drawing book to show their creativity in order to satisfy that part of the rubric. The UC comments that "if the students who read it come to the first class with a particular mindset that can positively affect the others if we e-mail them earlier".

Most of the actions suggested that this phase be implemented before the semester started. However, the effects of them were observed throughout the semester.

5.2.1.2 Changes in the Unit Outline

Negotiations were done with the UC to put more emphasis on creativity in the MD unit. This resulted with some regulation of the unit outline by doing small modifications. The first week was planned to be allocated to an introduction session of design and creativity. The next 2 weeks were planned for the idea generation process, where students would be encouraged to come up with alternatives to given problems. For increasing the feedback sessions in class, the UC included reminders to the weekly schedule of the unit outline such as "Show proposal to tutor and discuss" on Week 3 and "Show refinement of ideas to tutor" on Week 4 (MEE30003-UO-2015). Having individual critique sessions was suggested on Week 5 with the instructors. It was expressed in the unit outline as "Submit drawings for review". During Weeks 3, 4 and 5, it was decided to introduce creativity tools in tutorials. On Week 6, it was planned that the instructors would check the results of student ideas after applying some creativity tools at home. Week 7 was modified to include concept presentations, where each team would be expected to present their chosen design.

5.2.1.3 Introduction to Design and Creativity Session

In the first week's lecture the UC mentioned the nature of engineering design problems. S/he told students that creativity was significant in this unit and in all engineering fields.

Ideally, creativity should have been introduced early in the curriculum such as in the first year. However, in this case, this gap needed to be closed. Therefore, there was a requirement to start from the beginning by asking 'what is design, why we need creativity how we can think creatively'. It was suggested making an introduction class about design and creativity in engineering process and show how we can benefit from creative thinking. These were suggested aspects to instructors about the introduction session:

- Start with a discussion of 'what is design'
- Remind everyone that creativity is expected from students in their projects
- Indicate that sketching can be helpful in problem-solving process
- Encourage students to keep a folio
- In order to create an engaging discussion environment, show real life creative engineering examples
- Encourage students to develop a few alternative ideas, not to focus on just one

After having this session, ME-I3 was interviewed about his/her experience. S/he's criticism was that some students were mark oriented and they just wanted to pass, and they thought "why do I bother being creative" if it is not going to be assessed.

Showing previous student examples to current students is believed to trigger student creativity and motivation. However, when the UC was asked to show some examples to students in class s/he rejected this idea, based on her/his previous experiences: "If they see a good example they will produce exactly the same. We have engineering students who trained to be procedural […] If they had a lot of experience in doing this kind of project, then you can say this is the kind of standard I expect and they look at it, they will be familiar with what you're showing them and they appreciate the standard […] If it's the first time, they won't understand the standard […] In this context it doesn't seem to help them to look at a problem and work out how to approach it" (UC). This argument supports the previous research: When they are shown a principle, engineers have the tendency to be fixated on that principle and use it in their solutions (Purcell & Gero, 1996). When the UC had previously shown examples to students, s/he observed that most of the students' solutions just looked like the one s/he showed in the first class. ME-I3 admitted that s/he did not show students previous year examples, because s/he "did not want them to limit themselves". ME-I5 was also sure that students will come up with the same designs. Torrance (1997) supports what MD instructors think. Giving and showing previous examples will freeze and shape their thinking. It establishes expectations and fixation among students, which becomes hard to break (Torrance, 1977).

Even though a folio was expected from students, an example of what it would look like was not shown to students. However, this case was different in PDE. In both PDE design studios students were exposed to works of the previous students. Students had the chance to clearly see the quality of the work expected of them in terms of modelling, sketching, or presenting. ME-I1 puts forward the benefits of showing examples: "If I show students a previous report, that will give them a clear idea of what a problem or what the problem or what we've trained them to do […] Getting them to look at other people's design, that allows them to actually do some thinking […] It does help them to think about things they've missed [...] I think students learn better from their peers than from teachers" (ME-I1). Therefore, showing some examples can help students to understand the expected quality.

5.2.1.4 Increasing Time for Design Process

It was previously observed that the tutorial hours were not effectively used for design progress: Students did not allow enough time for an idea generation process in which creative thinking starts. Therefore, it was suggested that instructors highlight the significance of the design process. Some students were aware that creativity happens during process: "You can use creativity in the process to explore different ways to solve the problem" (ME-S7). However, "very little happened in tutorials within the first 5 weeks" (2015-MD-SFS). Students also highlighted the importance of getting early feedback: "Creativity comes in the early stages of the project or when you need to change something. Give students more choice. We've given the gear-box and started to learn about gears. It was just a straight line to follow. If we've been given ideas how to be more creative […] before everyone settle on their ideas. Then it's hard to change someone's mind" (ME-S7). That is why the examples shown on the first day are important. One of the instructors said "If we can give them a few more tools within the subject as to how they actually start a design, where to begin, because I think it's the beginning that's the difficult thing for most students." (ME-I4). Therefore, creative tools were provided later on in the semester. Instructors suggested helping students in their time management by reminding them to keep their sketches, for generating enough alternative ideas and by checking their work regularly to make sure they're on the right track.

5.2.1.4.1 Tutorial hours

It was suggested that more time should be spent on design as this was a design subject. For balancing the time allocated for the design of the project and technical issues the UC indicated that one hour of the tutorials will be devoted on design project and one hour will be devoted to weekly exercises. S/he indicated in her/his e-mails to students that the tutorials would be in two sections "to make them understand the week's topic and to progress the project". However, it was observed that this ideal situation rarely happened. The instructors did not put too much emphasis on the second one. Because, most of the time has been spent on solving the tests, repeating the lecture notes and preparing for the exam. In the studied tutorials, any time left after going through the book or solving the tests was devoted to student projects, if students wanted to ask something. Even though, instructors agreed on the importance of the concept generation, they did not do much in class to encourage students to generate concepts.

It was observed that the students mostly focused on the final product. They were not expected to develop their projects in class or show their design process to their instructor. In one of the tutorials, the instructor was summarising the chapters by highlighting the key points in the book, giving all the necessary information in a 'fill in the blanks' format. The students were copying what s/he wrote on the board. It was interesting to notice that nobody talked, everyone followed what's been written on the board, unlike in any other tutorial. It was observed that, except in that specific tutorial, other instructors were struggling to keep the students in class for two hours. According to the UC, students were accustomed to procedural learning; they prefer being told what to do and to copy whatever the lecturer says. The instructor (ME-I4) admitted that it was an “old fashioned, but a working” style. S/he said that students like it. It is understandable that students prefer someone who reads the book and summarizes it for them. One student stated, “tutorials outline the material in a greater and more relevant manner” (2015-MD-SFS).

When the reason for this situation was asked of instructors, ME-I4 declared “Because they (students) need technical knowledge for the industry, I try to prepare them for professional life” (ME-I4). However, ME-I5 contradicted that idea with: “The lecture should cover the theory and I think the tutorial should aim to get the students to practise what they have learnt in the lecture” (ME-I5). When instructors were expected to describe the typical content of their tutorials, ME-I5 declared that s/he “did not spend a lot of time on redoing the theory” because s/he thinks that “should be part of the lecture. But […] because the students were very unprepared for the tutorials that you end up doing that anyway […]. So I tried to give them as much information as they needed to be able to solve the problems” (ME-I5). ME-I4 stated that s/he split the time into two: “I spend an hour on the learning from the lecture and then I usually try to spend an hour on their design project”. In the first couple of weeks ME-I4 did not send any team who did not show the progress of their design projects However, in the following weeks, this habit turned into checking student works only if they had any problems. The students rarely had questions about their design works. Even if one hour of the tutorials was allocated for the design works, there was not enough time to discuss them with every team.

The observations are associated with the survey results that can be seen on Figure 5.2, which show students’ priorities in the tutorials. Students were expected to rank the most important reason for attending the tutorials in the written survey. They were expected to choose between 1 (least important) to 5 (most important). Based on the results, the least important reason given was “designing the design project”, whereas the most important reason given was “preparing for the exam”.

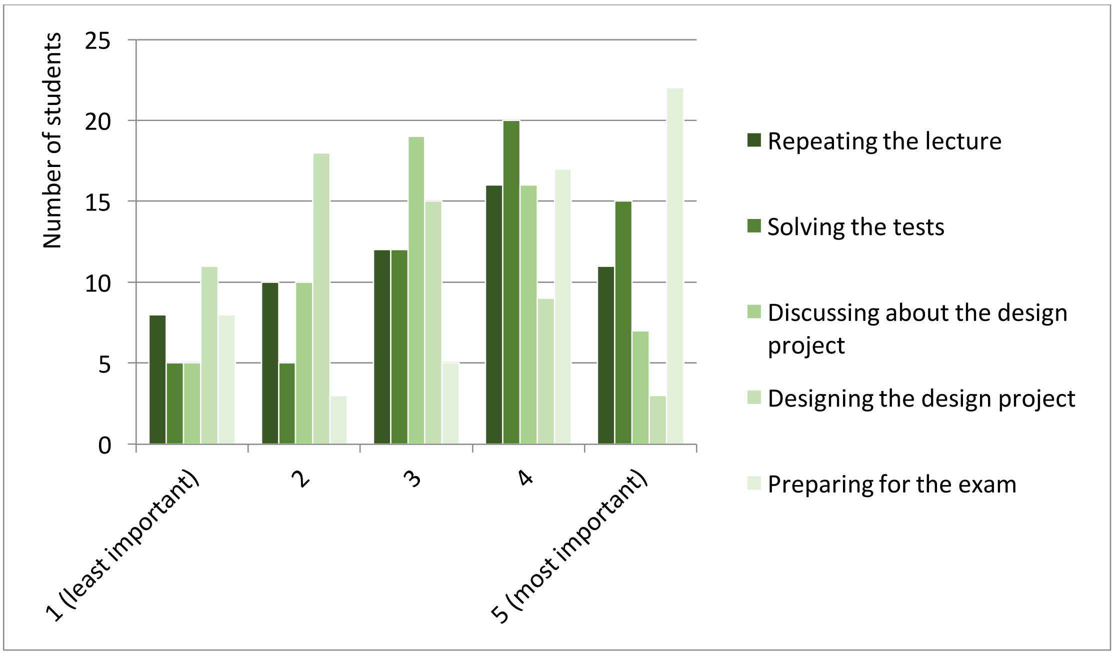

Figure 5.2 The reason for attending the tutorials

Apparently, tutorial hours were mostly allocated to prepare for the exam and to solve the test questions. As the unit has an exam component that is worth 40% it is understandable that most student effort goes towards the preparation for exams.

In order to get full benefit from the tutorial hours, ME-I5 suggested clearly indicating the requirements to students and dedicating the second hour to project design. "Two parts of the tutorial which I think is a good idea, the first one is for them to do some practical problems and then the second part is to help them understand their, or to work with them on their design" (ME-I5). Otherwise, students would like to spend more time on technical issues. If tutorials were used more to develop the design project, it would give two advantages:

- For instructors, to see students' progress and to give support during the design process.
- For students to generate alternatives, to see and learn from each other's work.

5.2.1.4.2 Forming Teams Early

It was suggested to simplify the rules of team forming to form the design teams as early as possible in the beginning of the semester for allocating more time to the idea generation process. However, the UC did not change any team forming rules. Because s/he declared that these requirements are for expanding students' exposure to different design attitudes as much as possible (MEE30003-UO-2015). Even though s/he sent several e-mails before the semester had started informing the students about the necessity of forming their teams in time, only a minority of the students came prepared. Sending e-mails prior to the beginning of semester did not work for everyone.

What made it difficult to build teams in the first week was the lack of PDE students and international students in some tutorials. It took time to communicate to other people in other tutorials to form the teams: "Trying to find people in the other tutorials is difficult because of the clashes" (2015-MD-SOS). Another issue that negatively affected the creative process was that the team members were in different tutorials. This did not allow students to generate ideas in class because their team members were missing. Making teams took almost the first 3-4 weeks of the semester, which is the most valuable time where idea generation is supposed to take place and where creativity occurs. The instructors supported this finding various times. ME-I4 mentioned that students had trouble in catching up when they were in different tutorials. The students also supported this: "If the UC would organise students into groups within the first two weeks and ensure that no student is left out by the 3rd week, I believe it would be very beneficial towards the improvement of this unit" (2015-MD-SFS). "Students who have dropped out of the unit due to having been unable to find a team or could not form groups in tutorials because everyone had formed them before semester started has been a very concerning thing to hear. In future, groups should be oriented around those who are in the tutorial groups" (2015-MD-SOS). "Group organisation has been a huge issue that resulted in many enrolled students dropping out of this unit before the census date" (2015-MD-SFS). Because the university encourages flexible learning, the UC allowed team members to be in different tutorials. It was observed that students used this situation as a justification for not doing any idea generation in class because their peers were missing.

5.2.1.5 Encourage Sketching in Design Process

Students have 2 hours of tutorials, which would be enough time for them to sketch during their design process. It was believed that, by sketching students would

- have something to put in their final folio/report
- not forget the ideas discussed
- start to practise communicating via the use of their sketches
- give feedback to each other after seeing the sketches

Therefore, it was recommended to the UC to encourage all students to sketch their conceptual ideas and to communicate with each other by drawing, no matter what the quality is, rather than just talking and discussing. When this concern was discussed with the UC, s/he said that the instructors can encourage students to sketch and to keep a sketch-book. On the other hand, most of the instructors admit that they could not expect students do something unless it was written in the rubric or indicated by the UC.

A few ME students indicated in class that they took a drawing unit in first year, which included a couple of weeks of hand drawing, but they had never practised these skills until the third year and therefore they were not very comfortable with drawing. As the report was a group submission, it was observed that only the PDE students did the necessary drawings. ME-I4's observations were interesting in finding out that ME students were more comfortable with basic sketching, whereas PDE students struggled more: "ME students did sketching better than PDE students by just putting their idea on a piece of paper. However, PDE students struggled, because everything has to be on a scale and absolutely good. PDE students are used to doing presentations in PDE studies so they put a lot of effort in it to make everything on scale and to look professional. However, ME students just did basic drawings, it was easier for them" (ME-I4). It is apparent that the quality of sketching expectation in PDE is higher than that expected in an ME context. At this point, showing examples to students can help them to understand the quality of what is expected.

5.2.1.5.1 Keeping a Folio

In the beginning of the semester, keeping a folio was suggested to students for their sketches and visualisation. In PDE design units, students were expected to keep all their idea generation and concept development process in a folio, which they submit at the end of the semester as evidence of their design process. This not only encourages students to sketch and to keep all their ideas together in a file, but also helps instructors to follow the students' design process.

Students also think keeping a folio is beneficial: "This subject would greatly benefit from being a folio unit, like most other design units." (2015-MD-SFS). "The fact that s/he has been pushing to make this subject more folio-oriented is something I can whole heartily agree with." (2015-MD-SFS). "I think that this unit is more fitting of having a folio" (2015-MD-SFS). Although the UC suggested students keep a folio a couple of times, it was not a formal requirement in the unit outline. In the rubric, "creativity" is one of the nine criteria for the report, and in the explanation of creativity "sketches will be useful here" is written in between brackets (MEE30003-UO-2015). The instructors admit that they expect drawings from students but this has not been clearly indicated in the class.

When students were interviewed at the end of the semester in what form they kept their ideas, the answers were: "a bunch of drawings in a notebook" (ME-S4), "between notes and drawings" (ME-S6), "first sketched, then we translated it to CAD after deciding whether it's a good or bad idea" (ME-S7). When their preference was asked between sketches and CAD, some students thought "sketching is quicker" (ME-S7), but most find CAD easier because "with the Solid Works it's easier to change things" (ME-S6).
ME-I5 admitted that s/he did not see "anyone keep a good folio, if they were given a folio and told to put things into it, that might be a little bit different" (ME-I5). "Keeping a folio is one of the best things they can do for their creativity and their design development […] However, the only kind of drawing that's taught these days is CAD. No one is forcing them to do sketch. Maybe we need to make it a part of the requirement […] Because of the technological advances in the last twenty years, doing anything with pen and paper has fallen by the way side" (ME-I4).

The results show that, just mentioning to students to sketch in the unit outline was not enough for the students do quality sketches or keep any type of folio. As PDE-I2 put forward "If you do not put the minimum pages in the rubric, you won't get them. Especially in early years they need to be told what exactly needs to be done". When the UC suggested "to submit a creativity folio", even the instructors did not know what it would look like, because it was not applied before. That is why, a folio must be described in detail.

5.2.1.6 Reflections of Phase 1

Even though these reflections were carried out concurrently during the observations, it is better to summarise them at this point. The results of the study show that more time must be allocated to the idea generation process. This can largely be done by solving the team forming issues and re-structuring the tutorials.

If a folio is expected from students, what is meant by "folio" must be clarified both to students and to instructors. Especially if it is something they have not done before. Showing previous examples will also help them to understand what is expected. If instructors are worried that students will be fixated with the shown examples, they should find relevant examples at least to show the quality of what is expected, rather to help encourage the creative process
without influencing the outcome.

Instructors should encourage students to sketch more, to keep a folio and to repeatedly show it in class. Otherwise, students will continue presenting their projects just with words or directly starting with CAD modelling. Even though each group has a PDE student, who would be familiar with sketching, each student should be expected to do sketching. Folios must be officially required from the students, rather than being just an expectation. It needs to be in the deliverables. In short, if tutors are expected to introduce something to the class to encourage students it must be in the unit outline as a formal requirement.

The structure of the unit needs to be updated, including introducing folio requirements and allowing more time for developing design projects. In order to allocate more time for design in tutorials, team forming processes and the idea of having a final exam must be reconsidered. Team forming rules should be simplified so that students in a team should be encouraged to be in the same tutorial. If the teams can be built in the first week of the semester, that would allow enough time to all for a fruitful idea generation process. Not everyone benefits from the e-mails sent before the semester starts, as some students enrol at the last minute. Therefore, the team forming process should not be expected from students without any support from the instructors. Having an exam at the end of the unit seems to inhibit students focusing on their design projects. Because of that, they cannot benefit from working on the design process in tutorials. Therefore, having a final exam in a design unit must be reconsidered with regard to increasing time for design and creative process.

5.2.2 Action Phase 2: Implementations

This phase comprises the weeks from 2 to 7 and tells about the small implementations done during the tutorial hours and their effects. These actions are about introducing and practising some creativity tools, doing regular checks and expecting presentations in class.

5.2.2.1 Introducing and Practicing Creativity tools

Previously in ME design units, students were just given a list of creativity tools and were expected to use one of them. Obviously, the instructors believed that students can read and learn about them by themselves. When it was suggested introducing the SCAMPER method to facilitate in class, it even took quite a time for the instructors to understand what that tool was all about and how it worked. Expecting students to learn and to apply a creativity tool by themselves is not realistic. The observations and interviews also showed that most of the students used brainstorming, which is the most popular and well-known creativity tool. Last year's approach revealed that just providing the names of the creativity tools and expecting students to use them were not enough. When the UC was asked if s/he was open to introducing any creativity tools in class rather than brainstorming, the response was "the instructors could work on these during the tutorials". However, it was observed that the instructors preferred guidelines about how to facilitate these creativity sessions.

As Mednick (1962) supports "massed work sessions rather than distributed", it was suggested conducting condensed creativity sessions, such as half an hour each week, at the beginning or end of the tutorial. Literature has many examples of "one-hour per week" creativity experimentations, which worked well (Allen et al., 1996; Panthalookaran, 2011; Adams & Turner, 2008).

Felder (1988) believes that “preparation” and “repetition” are the most important factors for the tools to be effective. First the students need to be given some background about the tools. At their first try, it is highly possible that the students miss the point, because of the fear of doing it wrong. Only after the second time, do they start to understand and by the third time most of them will start catching on (Felder, 1988). Therefore, it was suggested practising the tools more than once: Introducing a creativity tool once in class with a simple question and facilitating a session for it, expecting the students to practise it at home for the second time and come with the results to next class. Then when they use the tool for the third time they will be more comfortable with it. Even though the UC and the instructors supported the idea of conducting creativity sessions in class, they were questioning the reason for repeating them a few times. Students’ first experience with design and creativity process was explained to instructors by Liebman’s (1989) analogy of “swimming lesson”: you do not directly throw the students into the water, because they first need to learn the basics to swim.

After introducing the creativity tools in class, ME-I5 stated that “A lot of them (students) misunderstood how to use the creativity tools. They thought they can understand from the slides, but when they actually tried to apply it, they had difficulties for the first time” (ME-I5). This argument strengthens the suggestion of practising the creativity tools under facilitation. It is better to at least practise the tools once in class and make sure the students comprehend how to use them.

Some creativity tools, which were compatible with creative problem-solving processes were chosen to be implemented: Brainstorming, the 6-3-5 Method, and SCAMPER.

5.2.2.1.1 Brainstorming

It was decided that every instructor would conduct a brainstorming session in Week 2. The intention was to introduce the tool with a simple question in class and expect students to repeat it on their own for learning it comprehensively as a skill. A list of questions for brainstorming were prepared in collaboration with the ME instructors (Appendix XXV). Instructors were provided with a guideline (Appendix XXVI) about how to conduct a brainstorming session in class. A piece of A3 paper was provided to students and instructors were expected to choose one or two questions from the list.

Although, it is important to relate the exercises to the unit context, that was not done this time. It was believed introducing creativity tools with simple design problems rather than dealing with larger scale engineering design problems would be easier for students to first practise the tools. However, it was observed that students found it unnecessary to apply them with irrelevant exercises. It seemed they did not see any value in it. The real reason was that they were not going to be marked for this effort.

ME-I1 said that brainstorming brought better ideas after a period of time; when the participants actually finished the easy, obvious, funny, and humorous ideas. This argument aligns with the research indicating that creativity needs time. Critical thinking and evaluating the ideas were also important in the brainstorming sessions. Many groups used mind maps or affinity charts and linked their ideas together.

About 60%. of the students participated in the general brainstorming as a whole class. However, when groups of 3 or 4 were formed it was observed that they all participated. Students also informed us that it was a productive session. It is apparent that in bigger groups some students preferred to stay silent, however within a smaller group, everyone shared their ideas. MindTools Ltd. (2009) suggests combining individual and group brainstorming for the best results. That is why the 6-3-5 method, which is believed to give equal voice to everyone in the group, was suggested in the following weeks. The findings of the current study are consistent with these of Paulus and Yang (2000, p. 77), who claimed that during brainstorming "participants may be unwilling to state some of their ideas because they are afraid of being negatively evaluated".

5.2.2.1.2 6-3-5 Method

It was decided to allocate half an hour for practising the 6-3-5 method in Week 6. This method was chosen because it was observed that not everyone contributed to the idea generation process during brainstorming, due to some people dominating in the units. However, 6-3-5 allowed everyone to think independently and to come up with ideas. Kazerounian and Foley (2007) argue that students should be motivated by educators to search for more than one solution, they should look for alternatives. The same list of questions was used for this session. The instructors were all enthusiastic, friendly and created a relaxed environment for students.

Students were all previously informed by the UC via e-mail that the coming two weeks (6 and 7) would be dedicated to learning creativity tools for them "to improve their ability to produce a good design, correct issues that they find with their first prototype and also get good marks in the section of the report related to this" (E-mail 14/04/2015). Students were told that this was just an exercise for them to understand how to use the creativity tool, so that they can apply it for their projects. Mostly, positive feedbacks were taken. During the facilitation, it was observed that most of the students preferred to write their ideas instead of sketching. Students found it fun, but a bit challenging creating three different ideas in such a short time. Some did not come up with enough ideas, instead they built on others' ideas.

ME-I4 evaluated the tool by declaring that "with 3-6-5 they could go back and either add things to the designs to improve them or to give some sense of assessment of the ideas that were being generated, as opposed to just coming up with ideas. That's why probably 3-6-5 was slightly more successful than brainstorming".

5.2.2.1.3 SCAMPER

It was decided to introduce SCAMPER, another creativity tool, in Week 7. The aim was to help students to modify their designs for further development. SCAMPER allows students to make small modifications on their designs to make them better, by looking at the problems from different perspectives, using the keywords provided. Therefore, it was decided to introduce SCAMPER during their design process. The UC explained to the instructors that "the idea is to get the students to use those tools after they find issues from their first design and they need to get creative to solve these issues" (E-mail 2/04/2015).

McFadzean (1998, p. 311) suggests that paradigm stretching tools such as SCAMPER should be used under the supervision of an experienced facilitator. Otherwise, participants might feel uncomfortable. The last 40 minutes of the 2-hour tutorial was allocated for SCAMPER tool training. Even though instructors were provided with instructions on how to participate with SCAMPER (Appendix XXIX), the author helped them in introducing and explaining the tool in class, how it was applied, and where and when it could be used.

The same tool was also introduced and practised in a 2nd year studio unit in PDE. It was observed that PDE students were taking benefit from SCAMPER by modifying and developing their design works, whereas ME students were a bit sceptical about using the tool. In the interviews, ME students indicated that introducing such a tool was late in the semester, because they already knew what they were doing for the final. Week 7 was the week that students sent their designs to be cut in the Computer Numerical Control (CNC) machine, so they were all confident with their designs and unwilling to change anything. One student admitted in class that “now we think our idea is the best”. It shows that ME students did not necessarily modify anything to develop their project, unless they have a working design. They were mostly focused on the performance of their product. The general approach was like, if it was functioning well there was no need to develop it more. This attitude is unlikely among PDE students though, who try to change the design and add something more right up until the last minute. ME-S6 admitted that tools “can help but we were just more concerned of getting something that works as opposed to making it look good or anything on top of that. So we were more concerned with the performance” (ME-S6). One student in class explained that the difficulty with this method was the restrictions of the design problem; they had so many restrictions that they could not do any modifications.

According to the instructor comments, applying the SCAMPER directly to the gear-box problem did not work efficiently. Because students thought it was something extra and they were not very open to developing their ideas if they already have a functioning final product. It supports the idea of introducing the tool for the first time with a simpler problem.

Figure 5.3 shows the student responses given to the use and efficiency of the creativity tools used during tutorials in developing their design projects. Students were expected to rate each creativity tool between 1 (not helpful at all) and 5 (very helpful). Survey results showed that students did not find 6-3-5 and SCAMPER as efficient and helpful as brainstorming. It validates what ME-I1 said about the lack of interest of the students towards the tools other than brainstorming. Because the students already knew about brainstorming from previous years they felt more comfortable with using it.

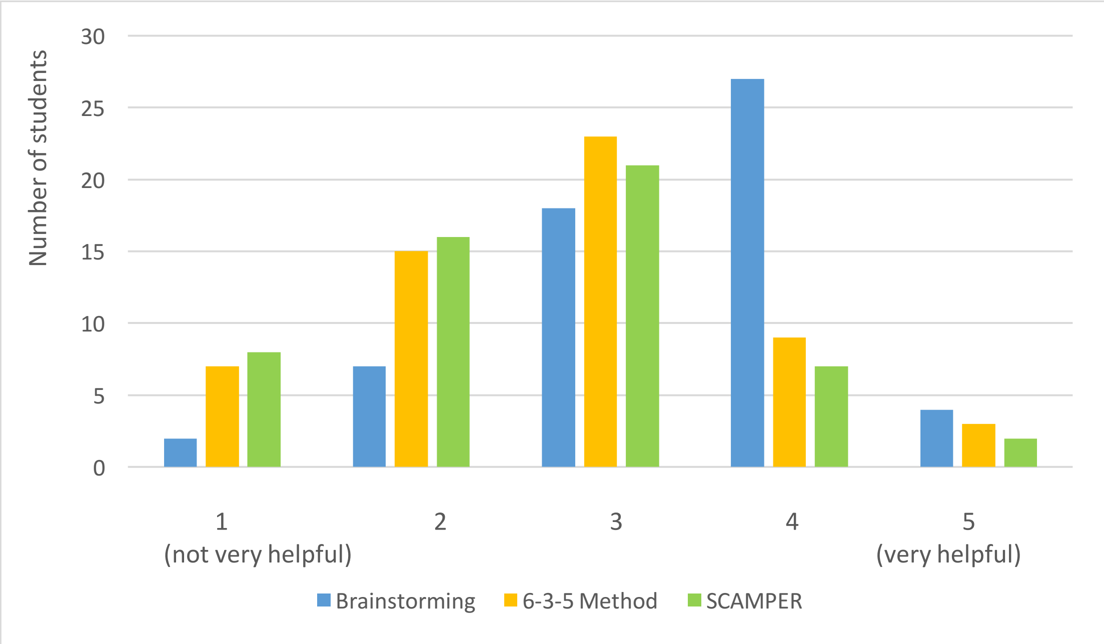

Figure 5.3 Use and efficiency of creativity tools used during tutorials

When it was asked of students at the end of the semester if they used any creativity tool during the design process, ME-S7 declared "We mainly used brainstorming. It was the best brainstorming session that we had. The whole design changed in two hours [...] We used 6-3-5 and SCAMPER in class. They were really good. But we did not use them for the design. We did not need them at that stage" (ME-S7). ME-S5 admitted that s/he did not take 6-3-5 too seriously, "because at that stage there's, it's hard to visualise our, all the problem before the thing is built. ME-I5 preferred that if students "come into the subject armed with creativity tools it might help them", because during the introduction time of the tools "they probably formulated in their heads what their design was going to be before they did too much in the creativity talk" (ME-I5). ME-I4 added that s/he felt the tools "were extra" and "needs to be embedded better" (ME-I4). "An overview of all the tools at the beginning would be useful, perhaps in the first week when we haven't really got into the design process… Because, I think that creativity in a lot of people's minds is brainstorming" (ME-I5). Overall, "a lot of them did go and use the things that we've been talking about in class to try and generate more ideas" (ME-I4).

5.2.2.2 Regularly Checking the Design Progress

Due to previous observations about the lack of guidance during the design process it was suggested that instructors increase their guidance and give more feedback to students. This can be achieved through regular checks of the students' works. It was decided in the instructors' meeting in Week 2 that each student team will be expected to come up with at least 5 ideas for the following week and the instructors would check them and give critiques. The aim was to see the students' design progress each week.

An interesting issue was revealed when it was asked of instructors whether they were following the development of the students' design projects. They said yes, but in practice, they had not really done more than asking if students had any issues. The general response to this question from the students was "we are doing fine, everything is OK". On the other hand, ME-S4 admitted that they had expected to get some feedback from their instructors about their design works when they submitted their drawings on Week 6. However, there was really just feedback from other students.

ME-I5 stated that s/he asked students to see the progress of their works: "There were at least three times where they each presented what they were doing with their design, and I also went around and talked to them about their designs and any issues that they may have […] but I guess if they did not want to talk about the design project, apart from those opportunities where they were asked to present, it was up to them" (ME-I5). ME-I1 admitted that s/he did not see any value in doing regular checks, unless the phases were written in the unit outline in forms such as concept generation, concept selection, concept evaluation. ME-I1 discussed the difficulty of talking with students about the designs: "All of them got obsessed with mathematical modelling and the test questions, in the tutorial that's all they asked me" (ME-I1).

There is inconsistency among instructors about checking student progress: ME-I4 did not want to interfere to the student works, found it more valuable to repeat the lecture. ME-I1 tried to give feedback, however students focused on other deliverables. ME-I5 did whatever students needed, if something was not written in the rubric, we could not insist on anything. ME-I3 knew the importance of creativity and design process, but because of the rubric, students focused more on the design product. These findings further support the idea of restructuring the unit according to expected outcomes for better consistency.

5.2.2.3 Presentations in Class

One of the suggested implementations was expecting the students to do regular presentations about their design works in class, during which they can get feedback from their peers and instructors. It is also believed to help students manage their time. It was decided that the students present their works during the idea evaluation and idea development phases, so that they could get feedback on how to proceed in developing their designs for the final submission. It was thought to be a good opportunity for everyone to develop their works. It was suggested the instructors encourage their students to present their work by:

- Providing an appropriate environment for seeing all kinds of different design solutions before the submission

- Learning from each other

- Getting different feedback from others to develop the works

- Practising presentation skills

Presentations were planned to take place in all tutes on Week 8. Students were reminded one week before via e-mail that they needed to present their final design concepts. However, it was observed in the tutorials that most of the students were unaware of that. In the observed tutorial, all groups except one presented and immediately turned off their Powerpoint presentation and sat back down allowing no time for anyone to ask any questions. It seemed that students just did it for the sake of doing it, which devalued the understanding and potential for getting feedback. Instructors could not expect students to make a presentation if they did not want to, because it was not written in the unit outline, there was no marks for that performance. Therefore, students did not value doing presentations enough. Even there were some teams who presented their design works, not all of them got feedback such as expected. In short, this intervention was not implemented in a proper and efficient way.

5.2.2.4 Reflections on Phase 2

When interviewed with the instructors about the ongoing process, ME-I4 declared "it was a good start to be able to expose them (students) to different ways of developing their creativity". The findings enhance our understanding of the use of creativity tools: It would have been more useful if all the creativity tools were introduced earlier in the design process and embedded in the unit better. Because once students were fixated by their ideas, they did not want to change them. Students and instructors supported this view during the interviews and surveys: "Creativity methods are introduced late to make any changes" (2015-MD-SWS). Almost all instructors supported the idea of introducing all tools at the beginning of the semester. First doing a brainstorming session, then a 6-3-5 session almost immediately after would be really good (ME-I4). Creativity tools were found to be useful, but need to be more related and integrated into the unit. It was decided to use similar tools next semester in the MSD unit, so that students will have more familiarity with them.

Students were also provided with creativity tool instructions showing how to use Brainstorming (Appendix XXVII), 6-3-5 Method (Appendix XXVIII) and SCAMPER (Appendix XXIX), which were introduced in class on Blackboard as learning materials. Students admitted that they can use these guidelines in their following units. However, just providing a list of thinking tools to students and expecting them to follow the instructions is not sufficient. Instead, students first need to understand the thinking processes thoroughly and it is the duty of academicians to teach processes and approaches to students for them to apply throughout their lives (Pappas, 2004).

The findings show that it would be better if instructors provided constructive feedback during the design process regularly. ME-I1 suggested attaching marks to weekly regular checks. Thus, students can be encouraged to show and share their ideas to get feedback. But, there must be consistency between the tutorials and tutors about giving feedbacks to student design projects. Therefore, this process needs to be embedded in the unit outline. Otherwise, students will approach to their instructors only when they have a problem.

Merely expecting students to do presentations is not enough. If presentations are believed to support the creative process, they should be formal requirements of the unit and must be encouraged. Instructors should also provide feedback during the presentations. Otherwise, they will not provide any benefit. In order to get presentations happening a part of the unit, the unit structure and workload needs to be reconsidered.

5.2.3 Action Research Phase 3: Assessing Creativity

This phase comprises the weeks between 8 and 12 and the process after the marks were given. It involves the assessment process.

The assessment of the Machine Design unit is divided into two: 50% for the design project and 50% for the tests and examination. The final gear-box design has always been assessed by performance in a competitive environment. Creativity is a part of the rubric for the reports.

5.2.3.1 Assessing Creativity within the Report

Students received marks for their reports, in which they were expected to write about their design process. Chapter Four mentions that the overall mark for the report would be the lowest mark of one of the sections (MEE30003-UO-2015). Even though the UC thought that engineers have to be good in every aspect, students argued that this way of assessment was not motivational: “The way our final reports were marked was unjust and unfair, seeing as the lowest score in any section for the report was our final score” (2015-MD-SFS). “I do not like the way the assessment is about report” (ME-S7). “This rule for assigning the entire report the lowest grade achieved in any of the sections of the report is extremely unfair as it literally wastes all the hard work input by the students” (2015-MD-SFS).

ME-I1 also supported what students thought about the assessment of the report: “It smashes their motivations; it doesn't help learning in any way. Students feel unnecessarily stressed because even when they have done something good, they were still not sure whether they have done enough because they are still afraid something might be wrong. So they feel unnecessarily pressured". The findings confirmed that the current assessment plan is not motivational, which is a pre-requisite for creativity. Although it was mentioned to the UC a few times that this way of assessment was observed to inhibit student motivation, the UC defended this way of assessing: "In professional life everything, every aspect has to be perfect, otherwise, it doesn't work". The UC (E-mail 4/02/2015) wrote to students "in the real world people will judge you on the worst you have done and the smallest failure in a system, so the rubric is to develop your ability to focus on doing everything well as an engineer".

5.2.3.2 Assessing Creativity within the Product

At Week 11 all of the students competed against each other. The set up was in a lab within the engineering building. The gear-boxes were all assessed on how much weight they carried in how much time. Instructors believed that having a competition motivated students. On the other hand, many students find the marking criteria of the competitions unfair as the marks were dependent on the others' performance, but not a standard level that you need to achieve. Student comments highlight this concern: "The gear-box performance scale is not indicative of student input: Gear-boxes should be ranked in order of placement, not by their achieved score. If one team does much better than the rest, then every other team suffers" (2015-MD-SFS). "I find wrong in this unit is that the performance of the gear-box mark that is received is scaled according to the placement of how well students did against their peers" (2015-MD-SFS). "This seems unfair to a majority of students as there will be a small percentage that has done well" (2015-MD-SFS). "The marking system for the gear-box seems unfair and does not necessarily reflect effort put in" (2015-MD-SFS). One student interviewee mentioned another point: "It would be more motivational if we see each other in the workshop right from the start" (ME-S5). Because competition day was the first time for the students to see each other's' works.

The instructors (ME-I1, ME-I3) were aware that the current assessment method did not encourage creativity: "Students need to have some evidence of using creativity and applying it […]. It needs to be more assessable" (ME-I5). However, they did not come up with any suggestions nor did they accept the suggested ways of rewarding creativity.

There are many methods for assessing creativity in engineering, as summarised in Chapter Two. However, the UC approached any suggested method. with scepticism. The UC said s/he was still unsure about a proper way of judging creativity fairly when the reasons of not assessing creativity in the final products were questioned. S/he thought that “the marks needed to be really rigorous” (E-mail 31/01/2015).

5.2.3.3 Assessing Creativity within the Process

As the instructors mentioned, how students came to their solution was not assessed. “Process needs to be assessed as well. Not one or the other, both” (ME-I5). ME-I1 responded that there was “a misalignment” between how they wanted the students to be creative and the way the unit was structured for them to do it. ME-I1 believed that assessment allocation needed to be given to the design process to ensure students take this area seriously.

Treffinger et al.’s (2002) matrix (Appendix II) was suggested as a measure for assessing the creative process as it provides criteria for creativity and explanations of all these criteria. These could be given to tutors as a framework for understanding how they can witness creativity and assess it during the design process. The matrix could also be provided to students as a rubric and a guideline to use for writing about their creative process in the reflective part of their report. Although this matrix was mentioned to students it was not embedded in the unit structure.

Another motivational aspect could be assessing creativity by description rather than numeric marks. Instructors can assess the creative process by using the four levels of classifying the level of expression of creativity suggested by Treffinger et al. (2002, p. 42-43). These categories do not have rigid boundaries and are classified as follows: Not yet evident, Emerging, Expressing, Excelling. This method was supposed to be used to assess the process rather than the final output but this suggested assessment method was not used or implemented. The main reason for that was that the unit outline and assessment plan has already been announced and it could not be changed in the middle of the term.

5.2.4 Final Reflections

If the end-of-year evaluation of MD is looked at, student comments were generally positive: “This unit is a fantastic combination between theoretical/analytical and creative thinking. More units should be like this” (2015-MD-SWS). Two survey questions were open ended, asking about the elements missing from this unit that would improve their creative thinking skills. The responses were diverse:

- Many students mentioned the lack of guidance: “More help from staff”, “we need more involvement from tutors to assist development of ideas”, “more coaching by the tutors and lecturer”, “guidance for how to complete the test and arrange groups for projects”, “most of the work is done solo without the help from the staff”, “less direction, did not really understand what was to be done until half way through the course” (2015-MD-SWS).
- Some students mentioned the inadequacy of the structure: “Design with creativity in mind is missing”, “needs a guideline to make sure we are on track or not”, “tutorials should be more structured to either design or the traditional style, current half method is ineffective” (2015-MD-SWS).
- A new design problem was another recommendation: “A more complex and new design problem would be better, there’s a couple of generic forms of how to build a Gear-box”, “we need something new other than Gear-box, continuing for so many years”, “more hands-on approach to creativity”, “more problems related to test and exam” (2015-MD-SWS).

It is important to address these issues in the next unit: Mechanical Systems Design.

Most of the students thought of freehand drawing as highly valued or very important according to the surveys, but they did not put too much effort in it as they were not going to be graded for this. PDE students were exceptional though. Even though the project was a team project, each student could be expected to submit a sketchbook including all of his/her thought processes with basic sketches, detailed drawings, notes, calculations, ideas created during creative sessions and results of the application of creativity tools. As all instructors supported the idea of making the folio an assessable part of the unit, it can/should be a formal requirement of the unit.

The priority of the unit deliverables can be modified. Students suggested it too: "There is so much design and analysis work, that having a 3-hour exam is not particularly fitting the sort of work that we do" (2015-MD-SFS). The unit needs to be restructured to considering more open ended alternative design problems, the focus on exam, regular checks and the workload.

When the biggest challenge during the design process was asked of students, ME-S5 said that it was to overcome the problems when making the physical thing. Many people got discouraged and stopped developing and building their ideas (ME-S5). ME-S4 mentioned another challenging point in the design process: "The transition from the idea generation point to the actual making stuff point […] because it's quite a big thing […] It can be a bit overwhelming and it was a bit tricky where to start and I think we kind of got stuck in that phase for a couple of weeks where we were just doing things that weren't actually beneficial" (ME-S4). These comments all support the fact that students did not get enough guidance throughout their problem-solving process from their instructors. There must be an agreement between the instructors on how to give valuable feedback to students during their design process. If instructors can create an environment where students can see each other's work, that will bring benefit in terms of peer learning too.

If creativity is expected from students through the process by keeping folios, doing regular presentations, or at the end through the final products, it must be reflected in the rubric. In short, creativity must be rewarded. A further study with more focus on creativity assessment is therefore suggested. The overall aim of assessing creativity should be:

- Encouraging students to be creative during the process rather than just focusing on the final performance

- Preventing students coming up with a common idea which is already known or already in the market

- Encouraging students to go through a diversity of ideas before deciding the best one

One promising result was indicated by the UC. S/he said that this year was the first time that the students asked if they were going to show four ideas to get a review. It shows that when compared to students from previous years they already had more than one idea. This whole process was also an important step for the instructors as they started to think about creativity and shared their ideas and suggestions with each other. The UC confirmed that it had not been happening before. This shows the implementations done so far have made students aware of creativity and creative thinking.

It was observed that when the gear-box projects were submitted the instructors said that there was not any surprising, creative results. When instructors compared the end products of this year and last year, ME-I4 found “this year seems to be less finesse, last year’s products were better”. “The students are very confused with the report, the rubric and criteria […] In terms of sketches, this is the worst I've seen so far” (ME-I1). The UC commented that he prefers more passion from students, s/he did not get it much this year. The results of the first Action Research process did not show a significant change in creativity among engineering students.

5.3 ACTION RESEARCH IN MECHANICAL SYSTEMS DESIGN

The suggested actions table, which was used for the initial Action Research has been updated for this part of the study. All the suggestions made at this phase depended on the data gained from the literature review and the results of the initial Action Research stage in MD.

The initial plan (Figure 5.1) was used again without much change. Some of the items could not be implemented in the first Action Research, such as making creativity a part of the assessment. This time, new modifications were added (Figure 5.4).

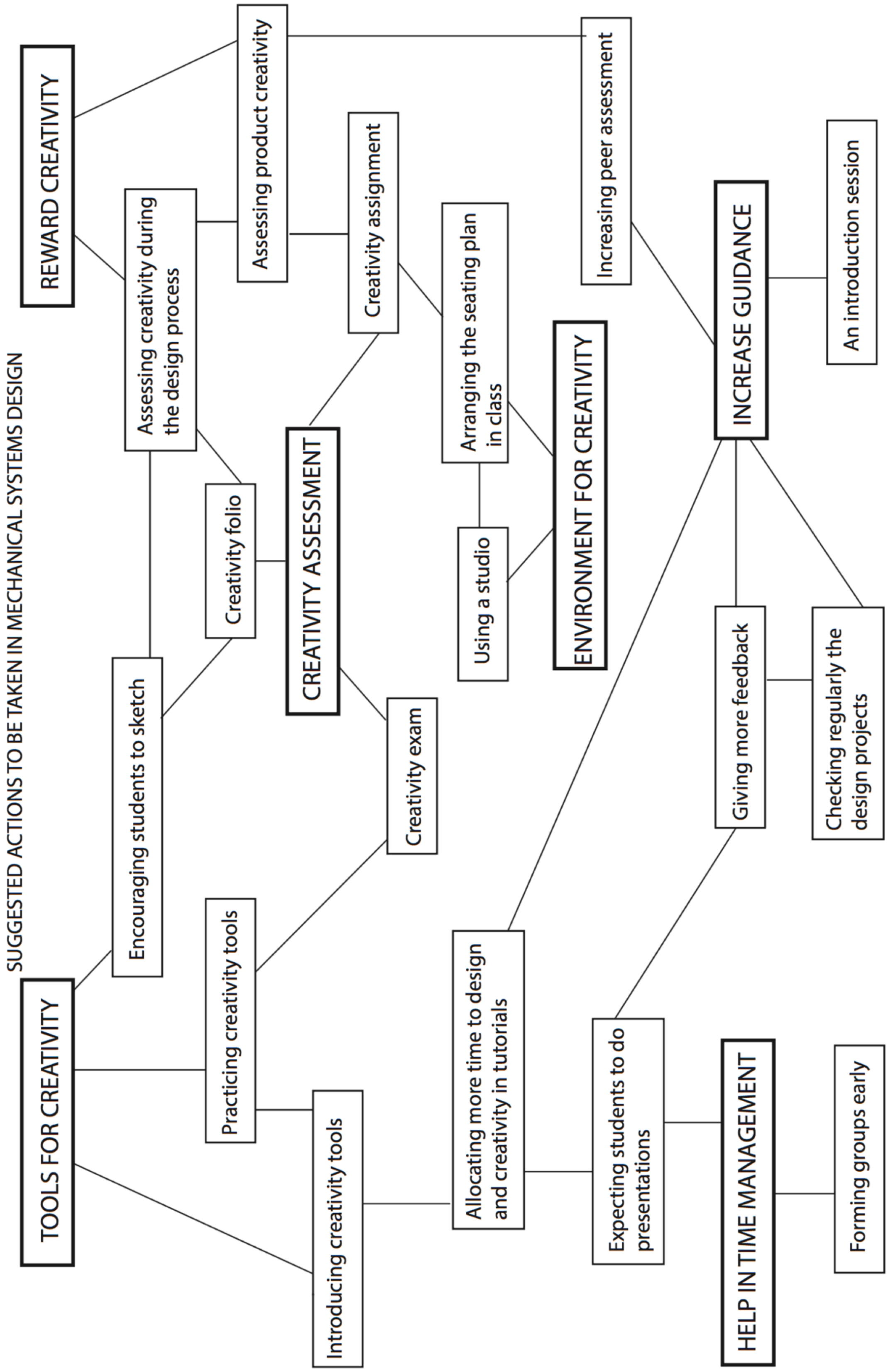

Figure 5.4 Interrelation of the suggested actions in MSD

Burns (1997) mentions the danger of the "outsider" or a "facilitator" researcher role committed to the Action Research. It is expected that the participants transform their own practices. The outsider researcher "has limited power to transform" and lives with the consequences of any transformations that occur (Burns, 1997, p. 360). This is exactly what happened during the first Action Research process. Therefore, the role of the researcher was changed for the second Action Research phase. As it was mentioned in Chapter Three, the researcher decreased her exposure to students in MSD after realising that her participation affected the behaviour of the students in MD. This was seen in some of the student comments in the surveys: "Tutorials wasted far too much time on the pointless exercises of a PhD Student" (2015-MD-SFS). "In the tutorial, more time was spent helping out some random PhD student's research rather than getting on with the subject material" (2015-MD-SFS). It was apparent from the student comments that they saw the creativity study only as part of the author's research, rather than as a benefit for their studies. This might have also happened because instructors pointed out the author at critical times, such as when doing presentations saying "Yasemin wants us to do presentations" (ME-I4).

A recent study by Cropley (2016) describes that just teaching students how to brainstorm or just introducing some creativity methods as being "short-sighted". Idea generation should not be thought of as a "declarative or a procedural building block" (p. 17), instead students needed to synthesise themselves and find ways of solving problems creatively (Cropley, 2016). Therefore, it was decided that the researcher would stay invisible in the next Action Research phase. Instead of focusing on creativity teaching to students, the focus would be on supporting instructors and understanding the underlying issues of creativity teaching by being in constant communication with them.

5.3.1 Action Phase 1: Pre-action Phase

This phase started a month before the semester until the end of Week 1.

After the meetings with the UC and suggesting that creativity needs to be valued and assessed during the class, s/he came with the idea of including creativity assignments and creativity exam questions (ME40002-UO-2015, p. 11) in MSD unit that need to be submitted individually.

The UC agreed talking regularly to all instructors to make sure everyone is on the same track. This semester, the UC prepared weekly instructions for instructors to administer in their tutorials. They were about what to do each week to provide consistency in between the tutorials. One of the issues, stated by the UC was that in the design process "the students don't understand how early they need to start". Therefore, for this design unit the UC decided to prescribe the tutorials for each week.

5.3.1.1 Examining the Unit Outline and Suggested Actions

The UC suggested defining the term creativity specifically for the engineering unit and setting the assessment criteria according to that specific definition so that the people involved will know what 'creativity' refers to in this unit. Because, it was observed that students had difficulty in comprehending the concept of creativity in an engineering context: "We had minimal guidance on this assessment apart from the vague, poorly written rubric." (2015-MD-SFS). However, a clear description of creativity was not given, instead, an introductory session to the design lesson was planned for Week 1 and given then.

In the MSD Unit Outline (Appendix XVIII), Week 3 was allocated for "generating alternatives and evaluating alternatives" for the given design problems. Students need time to first generate the ideas, then to evaluate them. One week is a very short period for doing both. If it was expected to generate and evaluate the ideas at the same time there would be little chance for the instructors to see different alternatives in class. Students would only show one idea. That was what happened last year. Because of all these reasons, it was suggested distinguishing the generation and evaluation phases by putting some time in between them, but that was not done. At least 2 weeks should be allocated for defining the problem and generating ideas.

It was suggested giving a more open-ended design problem or asking the same problem in a broader way instead of saying "develop a solar powered boat using the solar panels…" (MEE40002-UO-2014). However, the UC said that because it's a part of a Solar-boat competition only minor changes can be made.

Creativity was embedded in the unit outline. Three out of nine parts of the report were related to the creative process: Concept generation, Concept selection and Concept analysis. The unit outline included a part for a creativity folio (p.10) and there was a rubric for it with sections named as, use of space, idea diversity, idea quality and idea evaluation development (UO-MEE40002-2015).

5.3.1.2 Team Forming

Depending on the observed issues during team forming in MD, some suggestions were given to the UC:

- The teams could be arranged by the instructors.
- A list with the names, contact numbers of students, their cultural background and course could be provided as ME-I3 suggested. So that students could easily communicate. Otherwise, it was observed that just telling students to go and meet people to form groups as the UC suggested did not work.
- Online learning materials can be used to support the team forming process. For example, the University of Queensland uses "Team Anneal", which is a "team formation software tool that allows groups to be formed based on specified constraints" (University of Queensland, 2016) for their first-year engineering design unit.
- The number of the students could be decreased to 3 in a team as all the instructors agreed that 3 is also possible in terms of work load. It is believed to give a quick start to the idea generation process. Plus, a smaller number of students in a team might avoid dominancy in the group mentioned by ME-I1 and ME-I3.

As a result of these suggestions the team building conditions changed, with a warning to students: Either you will make your team or we will do it (ME40002-UO-2015). Therefore, students were expected to find their teammates again for the MSD unit.

5.3.1.3 Introduction Class on Design and Creativity

The UC explained the purpose of the unit to instructors in unit information: "To create a shared appreciation of what creativity is and how it can be used to improve engineering and engineering design […] This is to improve student performance in the project and get students thinking about their own engineering design abilities" (ME40002-UO-2015).

The first week of the semester was dedicated to discussion about design, design thinking and creative process. The UC wanted to discuss the following questions in groups:

- Why engineers need creativity?
- What examples can be thought of from industry and history of engineering creativity?
- How does creativity fit with design?

Before starting to discuss creativity, students need to learn what creativity is. Therefore, it was suggested giving a definition of creativity to students in the study context of the MSD Unit. Treffinger et al. (2002) also suggest giving students the characteristics that are most important in the understanding of creativity. The definition can cover the criteria for a creative product, so that everybody will know what 'creativity' refers to in this unit.

All instructors were informed that they were to give a discussion session on creativity and design in the first week of the MSD Unit. The UC gave many options to the instructors to choose from to show in class, for example a series of many documentaries on design and engineering about which they can discuss creativity. The individual interviews showed that the instructors struggled in finding appropriate examples to fit the class needs and show the students. They showed different examples such as a YouTube video or examples from previous works. All this showed is that instructors should be provided with good, but most importantly, specific examples, not a list of documentaries to go through to choose the most suitable one.

5.3.1.4 Assessment for Creativity

The discussion about increasing the percentage of marks for the design project in the unit was mentioned before. However, like ME-I1 argued, 'just increasing the percentage for the design project would not solve the problem whereas identifying creativity as a criterion for passing the design project and allocating a certain percentage of the marks would solve the problem.

The UC's biggest concern about the assessment of creativity is the issue of objectivity. S/he highlighted the importance of having an objective tool that can be used by the instructors. Students can also use this issue of objectivity to argue for a remark: "With something subjective, the student has no recourse. Students should be confident that they can understand why we mark the way we mark […] This type of marking will be different from a performance mark where we use an independent system to provide a score. Whereas we need to be able to justify the mark we give" (UC). So, it was suggested that the UC should rethink about the balance of creativity within the design project.

5.3.1.5 Environment for Creativity

From previous observations, it was concluded that the general atmosphere in the tutorial classes was not suitable for team discussions. Therefore, it was suggested providing a better and more suitable environment to students for team discussions.

A room with easily removable furniture can provide flexible arrangements for a group discussion setting. When students were asked in the written survey to describe a classroom setting in which they think they will be more creative most of them mentioned a seating plan where everybody can sit "facing each other". Respondents noted that they prefer an "open space design" with "modular desks" which give the possibility for a round the table group discussion.

Instructors should also get the advantage of a design studio, where students and the instructor discuss student's work in progress, the instructor moving from group of students to the next group for brief discussions on a regular basis (Goldschmidt et al., 2010). Because, a design studio provides an environment of allowing rotation of the chairs, that are easily moved, and rearranging the boards or tables for different aims like drawing, listening, discussing, presenting, individual work or group work. Using one of the design studios at the university, which is mainly occupied by design departments, would provide benefits to the MSD Unit. However, a design studio could not be arranged due to the priorities of other disciplines.

5.3.1.6 Reflections on Phase 1

According to instructor comments, the introduction of the concept of creativity to the unit went well. Students were more receptive to concepts of creativity and creative thinking from their prior experiences in MD. They all had quality introduction sessions and the instructors indicated that students were aware that creativity was highly valued in this year.

When instructors were asked if they saw any difference in this year's approach, ME-I4 stated that "the tutorials are now prescribed as to what we are to cover this semester". S/he added that "This is a fourth year subject. I think they should be more responsible for their learning now" (ME-I4). On the other hand, all instructors agreed on guiding students throughout their design process and keeping records of every team. The assessment method for the design project was not changed, but new creativity assignments are added to the unit. On the other hand, ME-I3 saw benefit in this new approach as now every tutor knows exactly what to do and this would provide consistency.

ME-I4 mentioned difficulties raised about team building due to lack of PDE students to cover all the teams. But, ME-I3 stated that "it took them less time to form a group than last year" (ME-I3), however, the issue was not completely solved. One student reminded us that "group members should be in the same tutorial class" (2015-MDS-SOS). "The grouping should be done using a random generator or something of a similar function. The idea of working in a group does not function well if the members chose their partners to their own liking […] In the real world you are assigned to a task within a group and have to work through the team dynamics no matter what the consequences are" (2015-MDS-SOS). According to Felder et al. (2000) the literature proves that teams formed by the instructor function better than the self-selected teams. Dutson et al (1997) argue that a random formation of teams simulates a real life situation. However, the UC indicates that s/he tried this method before, but students complained as team members did not have common meeting times, which resulted in an ineffective design process. This shows, no matter which method is applied, either assigning students to groups or leaving students to form their own groups, there will always be student complaints.

It was not possible to investigate the significant relationships of environmental factors and the creative process
because a design studio for the tutorials could not be arranged. Further research might explore this relationship.

5.3.2 Action Phase 2: Conducting and Evaluating the Implementations

This phase comprises the time between Week 2 and Week 10. During this phase the researcher was in touch with the instructors both by weekly meetings and with one-to-one interviews.

5.3.2.1 Tools for creativity

As literature (Felder, 1988) recommends applying creativity tools at least two or three times to learn them comprehensively the process should include the following steps for introducing and practising the creativity tools:

1. Introduce a particular creativity tool in class and practise them with simple problems in order to learn how they work in the first 20 minutes of each week.

2. Give a creativity exercise as homework to practise and to be marked afterwards.

3. Call on the students to apply the tool in class in later weeks when working on their design projects.

Instructors could indicate and repeat a few different times that they expect sketching, drawings from students and encourage them using a sketchbook. ME-I5 previously suggested that "it might be good to integrate these creativity activities into key submissions". Under the light of all these suggestions the UC added new assignments in the unit where students can practise creative thinking by using these tools.

The second week of the semester was dedicated to the idea generation process. Therefore, it was suggested to the instructors introducing and encouraging students to apply a few of the creativity tools in class. It was left open to instructors to choose the tool they believed was good at this stage. Examples were provided: the 6-3-5 method, SCAMPER, Random words, 5 Whys, 6 Thinking Hats. The aim was to break the student habit of using only brainstorming as a creativity tool as brainstorming does not really provide more than coming up with many crazy ideas. Therefore, students needed to be equipped with other tools too.

ME-I5 declared that s/he tried some new creativity tools other than 6-3-5 and SCAMPER, because a number of students did MD last semester and they already knew these tools. S/he introduced 6 Thinking Hats and 5 Whys. ME-I4 introduced 5 Whys. After applying the tools in class, ME-I3 asked students to apply them at home with other examples. ME-I4 pointed to another issue and stated that a good list of scenarios for applying these kind of creativity tools was required in both units. S/he believed that it would help students to work with a variety of different scenarios (ME-I4). These comments suggest that providing a quality list of design problems is as important as providing the creativity tools.

5.3.2.2 Presentations

It was explained in the unit outline that: "Each team will present their folio, the tutor will need to allocate time based on the number of groups present so that the 2 hours is properly used […] General feedback on how each team can leverage creativity more and what was done well will be given by the tutor at the end of the respective presentation" (MEE40002-UO-2015). Two of the tutorials were observed during presentation week in week 5. Even though there was not any mark for the presentations, all students did it because it was a milestone in the unit outline during this semester. Students came to class prepared with A3 paper or sketchbooks. This shows that when folio work was required and formally written in the unit outline, students take this part of the process more seriously.

Presentations went well as everyone presented with no hesitation in the observed unit. Everyone had their sketches/ideas on either A3 or in a digital format. This semester the presentation sessions were beneficial for students: "The presentations were variable, but more importantly you could tell they had spent a lot of time doing their literature review and discussing technologies and alternatives" (ME-I5). Some students were impressed by others' presentations and asked if they could improve to resubmit. It shows that the ones who did quality presentations motivated them.

One interesting observation was that some of the ME instructors did not volunteer to be involved in the students' decision-making processes and preferred to stay silent during the presentations. They did not ask any questions of students, did not help students to choose their ideas, did not indicate the ones which has more potential, or the interesting and creative ones. When it was asked of instructors about their approach the general response was that they did not want to influence the students, but on the other hand, students were expecting feedback from the instructors.

One of the reasons for this reluctance of the instructors to engage with the students is that this is the first time they were exposed to such an experience. Neither had the students given any presentations before in an engineering design classes, nor had the instructors listened and marked student works during presentations before. Pin up sessions, critique sessions or presentations in engineering are all new concepts in this context. Therefore, there needs to be clarification as to what exactly is expected for presentations, in what format, and to be delivered in how much time. The students do not know how to do prepare presentation slides because they have not done it before and instructors should be encouraged to provide feedback to students, depending on the instructor's previous industry and academic knowledge.

5.3.2.3 Creativity Folio, Assignments and Exam

The UC introduced three new deliverables this semester: Creativity folio, creativity exam and creativity assignments.

One of the requirements of the MSD unit was a "creativity folio". However, neither the students nor the instructors fully grasped what was expected as a folio. They wanted a clear explanation about the requirements of a folio, along with examples of what was submitted before. Due to the fact that a folio was not a subject requirement before, previous examples could not be provided.

ME-I5 stated that some students "put a lot of effort into folios, then got very disappointed at the end. They even bought a folder for it. But then we never asked for it [...] They presented their works in A3, they asked what they're going to do with it. They did not submit it as A3, they had to fold it to A4 and squeeze it in the report". S/he added that students were "disappointed that it wasn't marked. They went through all the effort and nothing really happened" (ME-I5). Even though sketching and keeping a folio for their design process was expected from students, folios were not marked separately, but just within the reports.

It was decided that the creativity exam would be a home exam, an exam that could be done in the students' own time at home. Because it was previously argued that creativity takes time, and it needs an incubation period. Instructors were told to make sure that students understand that there was no wrong and right answer when talking about creativity. So this exam should be put in a format where the students will have the chance to think creatively and produce a written example of their ideas for a solution to the given problem.

Students mentioned that the high workload of the unit inhibited them from focusing on their design projects: "The amount of deliverables was incredibly high with them being every week or two which took time and focus away from the solar boat construction and from other units" (2015-MDS-SOS). "Rushing all of the assessments, bunching them into a few weeks. Finalising a big group report, then only a few weeks to build our boat, then another assignment before we run the boats. This unit would be easy, if we didn't have a full load of units to do" (2015-MDS-SOS). "Too many assignments. workload of this unit is way too much. Very difficult to manage other units while doing this unit" (2015-MDS-SOS).

They were also not happy with the assessment weighting of the unit: "For a course that demands so many assessment milestones, exam weighting is too large, and very little help is given for its preparation" (2015-MDS-SOS). "The solar boat project is not weighted enough for the work that has to go into it" (2015-MDS-SOS). "The marks given for the boat project are way too low, given the amount of time it takes. It is very time consuming and difficult, and it has the same mark value as a test that takes half an hour" (2015-MDS-SOS). These comments support what the author suggested at the very beginning: Decreasing the assessment proportion value of the exam and increasing the assessment proportion value of the design project.

After the semester finished, ME-I5 commented that everything was a bit disjointed: "They had to do presentation, and they had to do a creativity folio, then they had to do creativity assignments […] They had to do it in the exam. There were four creativity assessments" (ME-I5). ME-I4 thought that due to many expected deliverables, students were just focused on them, but not the whole picture. However, the UC explained that "If you want to improve creativity, probably you need to do all of them, because it is new for all of the students. Because we mention creativity so many times, students think about it". Even though the arguments of these instructors contradict each other, with a thorough restructure, deliverables related to creativity can better be embedded in the unit structure.

5.3.2.4 Product Creativity Assessment

The final design project, Solar boats, in MSD would be assessed according to their performance, as written in the unit outline. It was decided to add an assessment of their creativity to the evaluation of the final students' works. However, as this was not written in the rubric or the unit outline it would be introduced to students as a 'bonus' rather than as a requirement.

The aim of this additional assessment method was to investigate if this type of reward for creativity being involved in the assessment process would motivate the students in their creative thinking or not. The UC indicated to students that it was an additional method of assessment for creativity and it would not reflect on their final marks. They were encouraged to participate in the creativity assessment, but were also informed that there will be no obligation to be involved. The teams who would like to be involved would have the chance to assess other's works and to be assessed by others in return.

The Victorian Model Solar Vehicle Challenge, which is a non-profit association, would provide a certificate to the winner of the competition event for racing their solar boats. The UC stated that "it would be good for the students' resume" to win the competition. They tried to enhanced motivation by extrinsic ways suggested by Amabile (1996) such as giving rewards and feedback for creativity. However, the announcement that there would be a creativity competition on the final day was introduced only three days before the actual competition.

The Creative Solution Diagnosis Scale (CSDS) is a creativity assessment method developed by Cropley and Cropley (2010a), which is used for a creativity assessment process. They suggest criteria to be used in things such as the creativity assignment and creativity exam. They would also be used as an explanation for the assessors. CSDS was found to be very consistent and reliable by the UC as it describes all the criteria. The main criteria are given in the order of priority:

1. Relevance & Effectiveness (R&E)
2. Novelty
3. Elegance
4. Genesis

The creativity indicators and their explanations in detail are given in Appendix III. Taking into consideration what Cropley (2010a) suggested about the priority of the criteria, a formula was designed in collaboration with the UC and added to the assessment. UC thought it would help students to better understand the relationship of criteria and the assessment in numeric form. The formula highlights the importance and hierarchy of the four main criteria: 5 points was divided like 2.5 for novelty, 1.5 for elegance, and 1 for genesis. The mark for creativity was decided to be based on the following formula:
R&E (2.5 x Novelty/100 + 1.5 x Elegance/100 + 1 x Genesis/100).

R&E was supposed to be either 1 or 0. The reason for that was because the UC, like Cropley (2015a), indicated that a design had to be initially effective and working in order to be considered for its creativity. Therefore, if the design solution did not pass the Relevance and Effectiveness part, it would be zero and there would be no need to assess it for its novelty. On the other hand, ME-I5 admitted that it was hard to decide whether the first part (Relevance and Effectiveness) was either 0 or 1 when assessing. ME-I1 questioned the reason for this: “It kind of suggests that a creative solution must work for it to be considered as creative”. ME-I1 gave the example of light bulbs that failed hundreds of times however they were still a ground-breaking discovery. “I think it should be adapted to acknowledge that creative ideas could still fail perhaps due to one oversight or another” (ME-I5). ME-I3 agreed with this argument.

Further in-depth interviews were done to understand the instructors’ perspective about CSDS. The responses were “straightforward, but very subjective” (ME-I5), having “too many criteria" (ME-I1), but "well-explained" (ME-I3). ME-I5 found it "easy to use", ME-I3 found it "difficult" because the reader needs to know exactly how the system works in order to assess. ME-I1 thought "it requires substantial interpretation of the indicators" and "interpreting the indicators will depend on the markers frame of reference".

Assessing creativity from a written page of problem solutions was not easy. Students were supposed to write solutions to the design problem. Students submitted their solutions in a written format. ME-I1 suggested to "rethink the idea that we can accurately assess creativity from reading a one-page" paper. The issue seemed to be about the lack of clarity in the students' responses: "Student should be failed by their words when presenting their ideas" (UC). Instructors stated that some of the works could not be understood by reading from a written page. Even though, some students explained their processes well enough, they were just explanations of what needs to be done, rather than what they have done (ME-I4). The trial with CSDS showed that it was challenging to assess the creative process from a written report, as it was not representing how the project worked, but rather how it was supposed to work.

The UC and ME-I4 pointed to the difficulty in deciding whether the design will work or the likelihood of it working. The criteria can be re-arranged and re-defined according to the given problem and what was expected as a solution. Cropley was asked (Personal contact, 28 Oct 2015) when he suggests using the CSDS. He responded that "it's probably helpful to the assessors to use the CSDS when they actually see the design, but if the activity is conceptual in nature, then obviously that's not possible. In that case, the assessor needs enough information to judge not how effective it 'is', but how effective it is 'likely to be'. This idea may also apply to other criteria in the scale – the assessor has to make a judgement on the design based on the best information they have […] It may be that the reliability of the effectiveness subscale is different when the assessors do not have the actual product in front of them, but are making an educated guess about the likely performance. In the end, however, the scale still enables the assessor to make a more rigorous and objective assessment of the product creativity".

Cropley and Cropley (2010a) argue that teachers who are using CSDS indicators to assess creativity had no problems understanding and applying it. In the context of this study, five instructors (four from engineering and one from industrial design) were expected to assess four of the randomly chosen student works about one assignment. During assessment, CSDS indicators (Cropley & Cropley, 2010a) were used. ME instructors agreed that the criteria were well explained, but there were too many of them. Although Cropley (2015a) argues that any person can assess the works, no matter if they are in the field or not, the author, having an industrial design background, struggled in assessing the engineering design projects due to a lack of knowledge about the technical terminology. Taken together, the results suggest that there is an association among the engineering instructors' assessments. However, further analysis is needed.

ME-I5 criticised that "the marking scale did not adequately assess the process used to generate ideas, the quantity of ideas, the way the ideas were presented, or the way ideas were compared and/or assessed". It is true that CSDS focuses only on the solution, therefore it would be better if this scale is used during the problem-solving process, when students come up with alternative solutions.

Because it was implied this assessment process had taken a lot of time and not all the instructors assessed all of the assignments due to funding issues, the overall response was poor. Several questions remain unanswered at present.

5.3.2.5 The Solar-boat Competition Day

The UC indicated that there would be an online survey where students could access the online assessment tool. However, during the competition day it was observed that students did not seem that they were interested in the creativity assessment as they were very busy with preparing their boats and solving last minute issues for the competition.

Even though the instructors kept saying that they need to assess creativity, they did not do the assessment either. None of the instructors who were there that day had a look at the boats to mark them for creativity. The UC confirmed that the issue on the competition day was that the students were very busy getting their own boat working, so they did not get a chance to really look at the other boats. "If we can be more organised and create an environment they can look at others and start to get benefit from that, we can get them to appreciate when they can see how creative idea allows them to achieve something, that's when this is going to work for them" (UC).

The UC, who suggested using an online assessment declared s/he did not do it because s/he did not have a mobile phone. ME-I1 said s/he was very busy with assessing the performance of the boats and thought that it was not expected from them. And ME-I5 stated that s/he thought it was just something for the students. When this situation was discussed with the instructors afterwards, ME-I5 argued that "it would be great for students to present their boats and have them on display and rated without the chaos of the race day" (ME-I5). It would be good if students "express themselves before the competition" (ME-I3), it will be a "better strategy for implementing both peer and expert assessments" (ME-I1). All instructors agreed that assessing creativity would be very chaotic on the competition day. This combination of findings provides support that the priority is on the performance of the products.

Only one expert from the Victorian Model Solar Vehicle Challenge came to make an assessment. However, s/he came after the actual competition. Although, s/he did not see the boats while they were competing and did not know the results of the competition, one of his/her three most creative design choices was one of the boats that performed best. The present finding supports, what the instructors acknowledged; that the last year's winning boat was one of the most creative ones. According to the students' choice of the most creative design, there seems to be a correlation between design products that perform well and creative designs. However, only less than 10% of students completed the assessment survey. Half of the students left the venue before the creativity assessment. ME-I1 confirmed that some works were not creative but won the competition and inversely the ones that were actually creative lost, because of performance issues. This contradicts what the UC said: "A good design is already a creative one". The study shows that there is not a direct relation between the best-performing design product and the most creative one. Due to the use of a small sample, the findings are limited. There were 19 boats in the race. Further research might explore the relationship between the performance and creativity in a product design.

If there is a correlation between the most creative boat and the best performing boat and if students could see this correlation, the author believes that it would motivate them. This is only possible if there is an environment where they can witness this. If an assessment of the design process is to be done thoroughly the instructors must initially value this correlation and should present it to the students as a component of the unit, not as an additional aspect.

5.3.2.6 Different Types of Design Problems

Open-ended design problems encourage students to think more creatively. Students identify the difference of these projects very clearly: "The gear-box had an objective which is the weight it had to lift […] You were going to get exactly these materials; you can use no more than that. Whereas with the ball-handling project you had to get a ball from point A to point B with no prescribed way of doing this. You can pretty much do that any way you want, using any material you want and any kind of process. So I think just the fact that it was a lot broader in scope meant that we had more opportunities to show off our creativity. Creativity was more essential to the project because you had to be able to look at it in a different way […] It needs to be kind of exciting and different. It needs to be something that is reasonably out-of-the-box and good to look at, whereas with the gear-box it was very much more like you have to do it this way and that's it" (ME-S4). "There is no creativity in the gear-boxes – It's more figuring out the maths, rather than re-envisaging how to make it. It's just making it work" (ME-S7). ME-S5 explained s/he chose the ball-handling problem, because s/he wanted "a physical outcome that is more fun than the standard one" (ME-S5). Similar to ME-S5, ME-S7 preferred doing ball-handling, however due to travel plans s/he couldn't commit to it: "I wanted to do ball-handling, I thought that might be really interesting, cause it's more open-ended, unlimited. The other one you just make a gear-box" (ME-S7). One instructor agreed that "there are very big distinctions between the projects in terms of how they allow students to be creative, the ball-handling project is the best challenge that will help them" (ME-I1). Instructors informed that according to their observations, most of the creative and motivated students dealt with the ball-handling project in MD, which was the open ended one. ME-I4 supported this by saying "ball handling's really interesting far more creative than the gear-box design". ME-I5 said that, "gear-box was difficult due to the restrictions. Whereas the solar boat you can come up with anything that allows more creativity. Gear-box is more engineering calculations, whereas the solar boat certainly allows more scope for creativity". ME-I1 supported that "The design of solar boat is more creative than the gear-box". This evidence shows that more open-ended problems, such as the ball-handling project or the solar boat project, enhance creativity more.

The distinction between the design problems was easily observed by the students. Even though the gear-box was a design problem, students found it more narrow ended, which inhibited creativity. It is apparent that the type of design questions effects the creative process in different ways. Defined and close ended problems, where the final product is obvious, did not allow much creativity. On the other hand, more open-ended problems encourage students to think more creatively. These results match those observed in earlier studies (Dutson et al., 1997).

5.3.3 General Reflections

At the end of the semester, instructors were asked to name the things that worked best and the things that could be developed through the changes implemented to enhance the awareness and development of creativity in the design process.

- **Creativity folio**

The folio expectations need to be clearly defined in terms of what needs to be included, in what format with a minimum idea of page numbers or content. This will provide a guidance to students and a consistent and easier way for instructors to make assessments of creativity. It is believed that if some creativity folio samples were provided, students and instructors both would understand what is expected.

- **Creativity assignment and exam**

Although, there was too much emphasis on creativity in the MSD Unit this semester by adding creativity assignments and exam questions, students main focus was still on the final exam (ME-I5). This shows that only adding extra assignments is not enough for fostering creativity.

Rather than having extra creativity assignments, integrating creativity into the main projects can bring better solutions. Like ME-I1 and ME-I5 suggested, the creativity assignment, the creativity exam, the folio and the presentations can be combined. This can be achieved through integrating expectations of creativity in the design project and evaluating creativity through folios and presentations. As said earlier, if these units are called design units, then the weight of assessment must be on the design projects, not on the exam.

- **Creativity assessment**

If creativity is expected from the students it is better to indicate this at the beginning of the semester. If any criteria for creativity assessment is to be used it must be explained from the first day of the semester, not on the assessment day, so that students and instructors will know what is meant by creativity and what is expected. Then they will have enough time to think and discuss the criteria. Students should be encouraged to take the criteria into consideration during the design process. Cropley (Personal contact, 28 Oct 2015) also sees "value in using the CSDS earlier in design, as a feedback tool, to help designers/engineers improve specific things".

If CSDS is a preferred tool, instead of making the Relevance and Effectiveness part either 1 or 0, the result of the performance competition can be used for the Relevance and Effectiveness part. Then this method can be used to assess both the performance of the final product and the creativity of the final product. Thus, students do not perceive the creativity assessment as an extra and it can be fully integrated into the assessment process.

- **The presentations**

If having presentations in class is being carried out the first time for both the students and the instructors, the requirements need to be clearly defined. Students need to know in advance the purpose of presentations, how long each team will present their work and what they should be talking about. Presentations must be standardised in terms of time and content. It is valuable to assess the student works during presentations, as they can reflect on their design process marks. In other words, this assessment can be part of the creative process assessment and will ease the instructors' job in the overall assessment. In the end, all of these presentation pages can be submitted within the creativity folio. As a result, the presentations, the assessments of them and the creativity folio can be integrated with each other as part of the unit content.

- **Creativity and design introduction**

Because students take MD before MSD, an introduction to a design and creativity session needs to be delivered in the first weeks of MD. More specific examples and some previous student works should be provided to instructors to start a discussion session in class. It will not only provide consistency between tutorials but will make it easier for the instructors who teach the unit for the first time. A recent study reports that (Zhou, 2012b) students had difficulties transferring the knowledge they gained in creativity training sessions to their problem-solving activities. Therefore, "creativity training should be a long-term and continuous element" of the process. It is important to provide creativity training to students, but making sure that they will apply these skills should also be of equal importance (Zhou, 2012b).

- **Creative environment**

The chance of seeing other students' design works should not be just available on the final competition day, but also throughout the design process. An environment where every student has the chance to see each other's works is believed to provide a good learning environment which can be realised through regular presentations and a less stressful final competition day.

- **Type of design problems**

It is believed that giving more open-ended design problems would trigger students' creative thinking. Another solution can be exposing students to more than one type of design problem. Even if the problems cannot be changed, some alternative solutions to the same problem can be shown to students. If students can see how many different and various alternatives can be designed for a problem this can help overcome their early fixation on common solutions.

- **Restructuring the unit**

There were student comments in the survey at the end of the semester indicating that the unit needs to be restructured: "A clearer unit outline should be produced", "Not very well structured. Too random in the second half, but I guess it is the nature of this subject" (2015-MDS-SOS). On the other hand, some think that the unit is already well organised: "All the information was given clearly in the unit outline", "It is very well organised", "The unit prepares us for a real engineering career", "I enjoy the self-directed learning and achievement that goes along with all the assessments in this course" (2015-MDS-SOS). This data must be interpreted with caution because not all students were in equal situations. The ones who took more than 4 units at the same time might have had more issues than others. However, according to the instructors' comments, design units need to be restructured in order to better integrate creativity expectation and creativity assessment in the unit.

5.3.3.1 Limitations of the Study

The aim of the study was to observe PDE education and get benefit from it where necessary in terms of enhancing creativity. The results of two phases of Action Research show that some of the suggested actions were implemented. However, some of them could not be implemented due to time or funding restrictions and context differences:

- Using de Bono's PMI method (Appendix XXX) was suggested for peer-review process during the presentations as this way of thinking may help students to think from a broader perspective. However, it was not used because there was not enough time for the instructors to read and respond to the suggested tool.

- It was suggested gathering a jury made of all the instructors for the assessment, but there was no convenient time for all and no funding to organise an assessment process like this.

- A design studio was suggested to be arranged for one of the tutorials to see how it effects student motivation and the creative process. However, it could not be arranged due to a limited amount of design studios at the university.

- Swinburne University of Technology, Faculty of Science, Engineering and Technology (FSET), works in collaboration with its Sarawak Department in Malaysia. Even though some changes in the unit outline have been proposed, such as eliminating the exams, it did not happen in the duration of writing this thesis. UC said that "It turns out that the application did not go through, and these changes will

> not be made until next year. By that time, we will try to remove the exam all together – to make it very much a project based subject" (E-mail 30/06/2015).

The reader should also keep in mind that the results of encouraging students for creative thinking could not directly be seen in the studied units. However, it is believed to help students in their future design processes in other units or in their professional life.

6 CHAPTER SIX: FINDINGS AND RESULTS

So far, this thesis has provided two studies in three stages. These studies presented the outcomes and the findings from each stage:

- Comparative study between Product Design Engineering and Mechanical Engineering (Chapter Four)

- Action Research in 1. Machine Design and in 2. Mechanical Systems Design (Chapter Five)

This chapter synthesises the outcomes from these studies to identify the broader results. It presents the overall findings about enhancing creativity in engineering education in three key areas:

1. Engineering staff approaches in enhancing creativity: This section covers the attitude of engineering staff and their approach to creativity related issues during the teaching of engineering design units. The findings in this section were explicit in the sense of being observed and being reported by the participants.

2. Instructors' understanding and beliefs about creativity: This part explains the underlying assumptions and beliefs of staff and students about creativity. The findings in this part of the study were not as explicit as the findings in the previous section. These findings were derived after interpretations of all the data.

3. Structural and organisational issues within engineering: This last section covers the structural and organisational challenges of enhancing creativity in a broader context. It looks at the phenomenon from a discipline structural perspective rather than focusing on the instructors.

The sub sections of the chapter ask questions and answer them based on the findings. These findings will be further discussed in Chapter Seven.

6.1 ENGINEERING STAFF APPROACH IN ENHANCING CREATIVITY

During the Action Research process, encouraging instructors to do something about enhancing creativity was more challenging than dealing with the students. It was observed that there was always scepticism from the instructors about the implementations, such as in relation to applying creativity tools, doing presentations in class, guiding students or assessing creativity. There was a misconnection between what engineering instructors thought and how they approached creativity teaching.

In particular, it was found that the engineering staff's approach affected the creative design process of the students. This section will focus on the instructors' attitudes regarding encouraging students to use creativity tools, to do presentations and to make sketches during the design process. It also clarifies the issues around rewarding creativity and guiding students in their creative process.

6.1.1 Are we encouraging students enough to use creativity tools?

The results of the study show that ME instructors did not encourage the implementation and introduction of creativity tools for idea generation and development during the design process.

The agreed plan among the instructors was to introduce and to practise using new creativity tools (such as 6-3-5 and SCAMPER) in tutorial hours. However, ME-I1 admitted that s/he gave the information about the tools to students to practise them at home because s/he thought that students were not interested in learning and practicing the tool in class. It was mentioned earlier by ME-I1 that s/he did whatever the students wanted in the class to keep their interest high. So, if the students were not interested in creativity tools they did something else. The results of the student surveys also show students did not find 6-3-5 and SCAMPER as efficient and helpful as brainstorming. This may validate what ME-I1 said in terms of the lack of interest of the students in the other tools. When this was raised all the instructors declared that they had encouraged the use of creativity tools. However, when it came to reports of this encouragement of the use of creativity tools it was found that they did not do more than mention the existence of some tools. This would indicate that engineering instructors should understand that only mentioning the existence of the tools is not enough. Creativity tools must be integrated into class activities and students need to be encouraged to use them.

It was found that the instructors were usually inadequate in their explanations of the use and benefit of creativity tools. Even though they believed in the positive effect of creativity tools in the problem-solving process, they did not indicate this in class clearly or adequately enough. It was observed that some of the instructors were unwilling to introduce or facilitate creativity sessions in class. During two different tutorials, both instructors preferred that the author, who was acting as the participant observer, should introduce the creativity tool (brainstorming) and facilitate the session in class. However, when interviewed, the instructors admitted that "they were not unwilling to introduce the creativity tools" (ME-I4) but preferred that the author run the creativity sessions because they wanted to "ensure the exercise fits well with the research" (ME-I1). Hence, the instructors requested the author to conduct the sessions. This approach shows that the instructors accepted the creativity sessions being run in their class more for the research rather than for helping students.

As a result, students questioned the reasons for learning about and practising with creativity tools and their future benefits. This can be seen in student comments: "Sick of spending our time in tutorials doing creativity tasks for a PhD student that whilst useful, will not necessarily assist me in passing the subject. I would much prefer to use my limited tutorial time to get more time with my tutor to find out about my project progress, the report, or more time for questions from the book" (2015-MD-SOS). One student said, "I feel that later in the semester when there weren't any creativity tools being forced on us, the tutorials were a lot more enjoyable and helpful" (2015-MD-SFS). If instructors explained the benefit of practising creativity tools adequately, the students may have benefited more.

It was mentioned in Chapter Five that students' main expectation from the tutorials was to get help for the exam, rather than getting help for the design process. Students seemed more worried about the final exam and did not give priority to the design and creativity part of the learning. Therefore, it is understandable that students did not want to spend their time using creativity tools in class. Another interesting point is that students preferred to take into account whatever their instructors told them, as the marks were coming from the instructors. The results obtained from this analysis show that the students needed to be informed beforehand about the benefits of using different creativity tools by the UC. This information needed to come from their instructors, not from any other individual such as a PhD researcher who has no effect on their assessment. It is argued that if the instructors had encouraged students to implement and practise creativity tools students may have benefited more.

6.1.2 Are we providing enough guidance to our students during the design process?

A major theme emerged from the findings that the instructors' guidance had an important effect on the students' approach to their design process. It was observed and also indicated by students that they need more guidance during their design process and creative sessions, in decision making, in team forming and in managing their time. However, it was a challenge to convince most of the engineering instructors that they should guide the students through the creative design process.

Collected data in this study shows that ME instructors misunderstood the concept of guiding. Some instructors believed that the students should make all the decisions by themselves. These instructors thought that guiding students was equal to making all the decisions on their behalf. It was previously indicated that ME instructors did not want to be involved too much in students' work, because they thought this was not fair. When the students declared that they needed more guidance the instructors said they did not want to solve the problem for them: ME-I4 declared that s/he "didn't want to influence students' decisions". S/he added that students "are already a team of grown-ups and I didn't want to interfere with what they were doing […] We are talking about engineers who are almost at the end of their education. They need to work on something alone without someone guiding their every step or they are useless when they get their first job for the next couple of years" (ME-I4). When ME-I4 tried giving some feedback s/he stated that the difficulty was "that you don't know how much guidance you give them before you've taken over a project and you're the one running it and not them". It was mentioned in Chapter Five that students highlighted the issue of guidance: "There wasn't much guidance from the teachers in terms of design, they were there to help with fundamental problems" (2015-MD-SWS). Apparently, instructors saw themselves more as technical support and assumed that their contribution during the design process would not be beneficial for students.

It was indicated to the UC that students needed more guidance during their problem-solving process throughout the semester. S/he explained that this was dependent on different learning styles, and that some students needed everything prescribed. It is important to be aware of the diversity of the learning styles of the students in a class to improve the quality of teaching. However, when we look at the big picture, we need to consider more than just fulfilling the needs of a particular kinds of learners. The UC stated that "Some students hate just being told anything. Giving them feedback if it's opposite to what they want, they will just keep on doing what they wanna do even more so". Guiding should not be understood as just prescribing to students what to do. For instance, in PDE the instructors did not tell students what to do but guided them by coaching, facilitating and supporting them in their problem-solving process. The study shows that ME instructors did not provide enough guidance to students during the design process.

6.1.2.1 Guidance for Feedback

The first aspect of guidance is giving feedback to students during their design process. It was found that instructors did not give enough regular feedback to students, which negatively affected the students' creative design process.

It was observed that students struggled during the design process They did not get enough support from instructors to complete their projects. They could not fulfil all the design steps, which caused creativity to be trivialised. Some students did not know which idea to go for or where to start the design project. ME-I4 supported this by saying "This is their first real design subject, so they struggle with what they are going to have to come up with" (ME-I4).

When students intimated that they were struggling in decision making during the design process the instructor's approach was very straightforward: "Just choose something and do it" (UC). On the other hand, the students' view was different: ME-S5 stated that "Until our level of bachelor degrees we still need to be constrained and guided in our process of researching and making or generating ideas. We need to be guided. We're not ready to just go off and go into something. If we come up with something, it would really help if the tutor or the lecturer can see the potential problems and because it may be a big problem and by the time that the group reach to that problem it may be too late". It is apparent from this quotation that this student was not expecting the instructors to make all the decisions for him/herself; s/he just needed some guidance and feedback in finding the path to follow their way.

One student's comment from the survey results explained the situation: "I like that this subject aims to give us initiative to act on our own [...] But I believe that this should have been made clearer sooner" (2015-MD-SOS). Another student's comment showed how guidance could help them: "I still feel like this whole part was taught by throwing us in at the deep end and hoping we get better. Some guidance on things like useful strategies to adopt would have been good" (2015-MD-SFS). "Being presented with an abstract problem without any guidance is very shocking. If this unit is supposed to help us learn how to do it, this is not the way to do it" (2015-MD-SFS). Student comments at different times repeatedly supported this finding: "If we'd had a step by step example at the beginning, things wouldn't have seemed so daunting. After that, if instructors want to say you're on your own folks, then okay. But at least give us something to begin with" (2015-MD-SFS).

When students were interviewed, ME-S6 said that they did not get any guidance from their instructor on how to build their design. In response to the question of what was missing in the unit, these were some comments from the Student Online Surveys: "This unit already has almost zero guidance" (2015-MD-SOS). We need "more guidance from the teaching staff for the projects" (2015-MD-SOS). "If there is no support I would end up sitting the lecture not really having any idea what to do" (2015-MD-SOS). Student Feedback Survey (SFS) results that were reviewed at the end of the year, supported previous comments: "The whole unit seems to be set up to teach us how to be good design engineers by letting us try to do a project and allowing us to learn from our mistakes. This isn't necessarily a bad technique, but I don't think it should be used in isolation. Guidance can still be given on good strategies, approaches and mindsets to adopt for design engineers" (2015-MD-SFS).

It is interesting to note that although the students preferred to be checked regularly during their design process, some instructors did not do this. ME-S7 specified that their team preferred to be checked: “First 5 weeks the tutor always wanted to see the groups after the tute. Then we only showed in every 2-3 weeks, if we need something. It was good in the first few weeks. It made us feel that we had to do it. If [s/he] hadn’t done that, we might be more slack and behind. I liked the way [s/he] asked. It puts a pressure on us. A bit of pressure is good”.

It is apparent that the instructors encouraged students to find their own way by allowing them to accomplish a project from start to finish. This is understandable as they are final year students. However, they were still new to design and the creative thinking process. If students had the chance to practise the creative design process in every semester before reaching this point, then the instructor’s current approach would be more valid. The author argues that it is possible for instructors to just give clues about how to proceed during the problem-solving process without interfering too much, as will be discussed in next chapter.

The UC indicated that s/he always thought, “the students behave maturely when they have an idea, they will talk to their instructors and engage with them and discuss”. However, what actually happened in classes was different. Students did not share their ideas with their instructors unless they were specifically asked to do so. Interestingly, ME-S5 stated that they didn’t even think about getting feedback from their instructors: “The tutor would be available for us to seek some guiding from, but I don’t know why we just completely ruled that out” (ME-S5).

When it was asked to instructors whether they were regularly following the development of students’ design projects, some say they did (ME-I1) and some say they did not (ME-I4, ME-I5). ME-I5 admitted that s/he tried to go around and talk to each team about their design projects, however if students did not want to talk, s/he did not insist. What generally happened in tutorials did not go beyond asking students every week if they had any “issues” regarding their projects. Most of the time students responded that they had no issues. The observations were consistent with those of instructors, who stated: “You don’t want to be assessing everyone’s design every week to say where is it, how is it going, how do you feel about it so I know where they’re at, but unless they specifically are struggling I don't step in" (ME-I4). However, ME-I1's thoughts are more positive on regular feedback: "My understanding of guiding students through an ill-defined problem-solving process is helping them appreciate the multiple routes they can take towards defining the problem, choosing appropriate methods. Once we are clear of the problem-to-be-solved, I will get into a consultation mode where students update me on their progress, preferably on a weekly basis".

Overall, this evidence indicates that if instructors had supported and guided students more than just being there, students might have experienced a more fulfilling creative design process. Some instructors did not understand the value of regular checks, even when students need it. Giving regular coaching and feedback to students provides an environment where students can ask questions and discuss their concepts and ideas. This also helps to encourage all students to be on the same track. This would eventually aid students in their time management, which will be explained next.

6.1.2.2 Guidance for Time Management

Another aspect of guidance is helping students in their time management, which is an essential part of the unit's purpose. It was evident from instructor comments that they believed creativity took time and it was a process rather than an instantaneous occasion: "We cannot expect students to be creative all of a sudden" (ME-I3) and "you need to sleep over an idea to actually apply it" (ME-I4). Therefore, students needed good time management skills to allocate enough time for the creative process.

It was observed that students struggled with their time management. However, the instructors did not give enough guidance for time management. This resulted in inadequate time being allocated by students for problem defining and the idea generation process. ME design units were not designed to consider the phases of the creative process such as that described by Howard et al. (2008). Time management was not mentioned in class nor mentioned in the unit outline.

The idea generation process, where creative thinking occurs and where students need to create many alternatives, was usually skipped, because the contact hours of big units such as MD and MSD were not enough for covering all the content. Consequently, most of the students directly jumped into developing their first and only idea. When students were asked if they evaluated any other alternative solutions to the given problem, ME-S6 admitted that "we just basically picked a design we thought would be easiest to translate into real life […] we mostly just build the design". Students were not fully aware of what to do next in the design process, which caused them to lose track: "Because the way they push the unit and try to make it look like it's about the product, we lost track of the process" (ME-S5).

Students indicated that they needed help in managing their time, because it was the first time they experienced the design process in higher education. However, the instructors did not find it essential to help them in that matter. The UC changed the unit outline in the 2nd semester by prescribing what to do in every step in the weekly tutorials. However, some instructors found it unnecessary this time: "I think students should be more responsible for their learning. I feel we're almost baby feeding them again and that they are starting to lack confidence in their abilities" (ME-I4). UC believed that students must be able to manage their own time, because it was part of the engineering process. Undoubtedly engineers need extensive time management skills; however, some guidance could help them to develop this skill in an educational context.

Time was needed for creativity, and this could only have been possible through effective time management. Therefore, it might be beneficial to help students in managing their time. Because if there is not enough time for the design process there would not be time for the creative process either. Engineering students were exposed to a design and build process for the first time in their four years of education. Hence, they faced some challenges, which was not surprising, as design thinking involved a different kind of thinking than they were used to. A closer look at the findings indicate that for achieving a more effective creative process, instructors should guide students in two ways: guidance by feedback and guidance for time management.

6.1.3 Are we expecting our students to behave like professionals?

One of the main issues with the challenges of enhancing creativity in the course are the high expectations from the students. ME instructors expected the students to behave more like junior/novice engineers. They expected them to decide everything about the design project by themselves and to manage their time without any guidance. It is understandable that the instructors wanted to prepare the students for industry and real-life conditions, however, this approach put pressure on students that was counter-productive.

The UC indicated to the students that they were “engineers” and they “need to make their own decisions” numerous times. However, it was indicated by the students that the idea of “you are an engineer isn’t helpful” (2015-MD-SOS). One student commented that “You can't just sit there and say ‘you are engineers; you need to figure it out’. I don't want all the answers provided to me on a silver platter and am happy to try and solve problems, but I would hope that if someone states an incorrect answer that it be at least noted that it is incorrect” (2015-MD-SOS). “I am tired of hearing 'if you can't do this, then you won't make it as an engineer” (2015-MD-SFS). Because of the instructors’ high expectation, students thought that they needed to solve all the problems by themselves and to finish the projects without any help from their instructors. As a result, students not only struggled, but also did not take any risks during the design process, which is an important necessity for creativity.

Even though instructors expected professionalism and accuracy in whatever students did, students on the other hand thought they were not professionals yet. Evidence from student feedback supported this finding: “Students were repeatedly told that ‘you’re expected to be a self-starter in the professional world and that you won’t have the support that’s offered at a university level’, but the teaching staff are failing to understand that students are not professional engineers yet and that we do need help along the way. If a student has exhausted his/her resources in trying to answer a question or complete an assessment item and approaches the teaching staff for help, they should not be given less help than a professional engineer would receive” (2015-MD-SFS). “Students are not real engineers. No matter how hard you try, students are students. The real world will turn them into either engineers or failures but it’s all within the student themselves. You are not capable of changing this fact” (2015-MD-SOS). The UC responded to these comments with an email: “If I say you need to be able to do something as an engineer, then you should take action to ensure that you can do it. I tell you this to let you know that you will need to work on it, and you can’t simply let it slide […] If I put a question back on you, then it meant that I can tell you know how to answer it and you need to develop an ability to have faith in yourself so that you can make decisions yourself like a professional engineer, and you don't really need another person answering it for you".

After many comments on the lack of guidance during the design process, the UC sent another email to students with a job advertisement attached. Two of the required items were: "Strong problem-solving and troubleshooting ability. Excellent attention to detail and a self-starting nature is essential". The UC explained that the reason why the project was left open-ended and students were left to manage themselves was so that they were "better in these two points" (E-mail 03/06/2015). ME-I4 supported this argument by stating that "we need to install a feeling of independence in the students to better prepare them for them for their working lives". The UC stated that s/he liked "the idea of the students making an independent call like a professional without the need for hints".

Students were pushed to behave like professionals and to make their decisions without the need of any support. This made it harder to give students guidance when necessary. ME-I4 explained that "If you have too much involvement from other people, then you start to have their ideas being pushed. Engineers across the board have a tendency to be a little bit egotistical and they usually think that they're right too […] So that you've already got a team of four different minds and four highly intellectual people thinking about this problem and they've worked out what's in the realm of their understanding" (ME-I4). This comment shows that expecting students to behave like professionals created conflict in the ideas of guiding and giving feedback to them.

The results seem to indicate, from an educational perspective that it might be a valuable approach to expect students to act like professionals. However, students needed support in creative thinking, if they were still in the phase of developing this skill. What instructors forgot about students is that they were still in an education phase. Instructors should have understood that students were not professionals yet.

6.1.4 Are we encouraging students to do presentations and to sketch?

Encouraging students to do presentations and to sketch in engineering design units were some of the issues that need to be addressed for enhancing creativity. Even though the instructors supported the idea and the necessity of students giving presentations, and of having sketching and drawing skills in professional life, they did not encourage students enough to actually work on these skills in class.

Presentations were thought to help students to get feedback, to learn from each other, and to be ready for professional life. Interestingly, even though the instructors agreed that giving presentations are beneficial they did not encourage students enough to do presentations. It was decided that all student teams would present their works in the tutorial for one hour and it needed to be an important aspect of that week's design class. However, the observations revealed that the instructors allocated only 20 minutes for the presentation by all teams in the class. Even though it was suggested that students need to give feedback to each other during presentations, this did not happen either. The instructor did not ask any questions nor gave any critiques on the presentations. Many of the students did not wait for any feedback. They behaved as if they just have to do it. Therefore, students did not fully understand the educational potential of giving presentations and getting feedback. ME-I4 explained his/her silence during the presentations by saying students "should be evaluating themselves, not me [...] They need to come up with a decision". When the instructor (ME-I4) said in the beginning of the class that "Yasemin wants us to do presentations", one student responded, "can we just skip this presentation if it is not in the unit outline". Squeezing all presentations into 20 minutes and then shifting into lecturing again shows that the instructors saw presentation sessions as an unnecessary extra requirement.

One of the students admitted in the interview: "I think nobody understand the benefit of it (presentations)" (ME-S7). When it was asked of the instructor, if s/he saw benefit in presentations, s/he replied "If they're five minutes or less. Students' time is valuable. It means that they're not learning, they're not keeping up to date with the work that they have to do and my time is again being eroded as to whether or not I can help those that are struggling" (ME-I4). The reason for this situation was related to the timing issue, as mentioned before. Some instructors and students thought that they spent their class time on presentations at the expense of focusing on technical parts of the course. However, ME-I5 saw presentations as very valuable in an educational context: "There's probably limited opportunity for them to do presentations, and it's something that's going to be expected from them when they are in the workforce" (ME-I5).

The only criteria set by the UC for the presentations was “something visual”. However, when the presentations were not projected on a screen but only presented from papers, it was hard for the others to see them in a class of 25 students. If the aim was to see others’ work and to learn from each other, presenting projected digital images on the board would have been required. Otherwise, a seating arrangement must be organised to make sure all students see what is presented. The UC supported this by saying: “What we need is students to see creativity working. They should think that guy came up with a better idea which is better than mine, because they are creative”. This argument supports creating an environment where students can learn from each other by seeing others’ works and this can be realised through watching and listening to their peers’ presentations.

Sketching and drawing are essential skills to have during the design process to help enhance creative ideas. However, it was observed that instructors did not encourage sketching either. The same thing happened with the sketching practice in class as it did to the use of creativity tools. Even though the instructors believed that sketching must be the initial step in designing this did not go beyond mentioning to students to keep a sketchbook and to sketch. However, there was not an official requirement for that. ME-I5 stated that students needed to submit their creativity folios, but they were only “marked in the context of the whole report”, but not according to the ideas they sketched. As a result of this low-key approach students did not value sketching.

It is apparent that some of the instructors did not encourage students to do presentations and sketching in class. If the instructors do not see the design process as valuable time for student development in terms of creativity, students do not value them either. The instructors, all of whom came from the engineering industry, were interviewed and asked if they needed to present their drawings and communicate their work in an industry context. They all agreed that it was a requirement in professional practice. So if the aim was to prepare students for professional life, presentations and sketching should have been a part of the unit too. On these grounds, it is argued that we cannot expect the students to understand the value of getting feedback through presentations unless their instructors understand this.

6.1.5 Are we rewarding creativity in engineering?

The interviews and observations indicate that instructors did not value assessing creativity. This made it challenging to integrate creativity in the assessment process. Even though the instructors believed that creativity must be rewarded it was not included in the unit. Instructors were asked if creativity was an assessment criterion for the design product. The UC, ME-I1, and ME-I3 all agreed that there was nothing about product creativity in the marking criteria. However, ME-I5 corrected that view, pointing out that creativity was noted as an assessment criterion, as students needed to mention it in the final report when writing about their design process.

When it was suggested giving marks to promote creativity, the response was, “a good design is already a creative one” (UC). Even though ME instructors declared that they were expecting alternative (creative) solutions from the students, they admitted that it was not a criterion for the final design project. One of the instructors said, “creativity was supposed to be part of it” (ME-I1), but they did not actually think about how to assess it. It was “not it in the assessment criteria” (UC). The instructors expected students to be creative but they “failed to capture the way they mark it in assessment” (ME-I1).

It can be concluded that students did not behave any differently to creative thinking than to any other subjects that were taught, their behaviour was simply assessment driven. Students were motivated by marks. It was mentioned in Chapter Five that if there was no mark for creativity in the unit assessment students did not push themselves to find more creative solutions. All the instructors agreed that students focused more where the mark was: “You see how everybody's so eager to do the test because there's a mark attached to it […] If we want to put in creativity in that, then we have to give a good mark to creativity just like we do with the test now” (ME-I1). This is similar to what the UC said once “if we do not give marks for tests, the students will not study”; if we do not give marks for creativity, students do not put effort in it.

The study shows that a mark being given for something was a source of motivation for working on that something, regardless of the type of assessment that was involved. However, creativity was not a part of the assessment and was not allocated a mark. As a result, there was a lack of motivation from students about working on creativity. As

ME-I3 declared "creativity should come from self-motivation". The findings suggest that in order to enhance creativity it should be assessed in the design process. If only performance is valued, then there is no point in embedding creativity in the unit.

To sum up this section, and rather contentiously, it has been found that many of the engineering instructors do not have the necessary skills to teach creative thinking in the design process. Although the UC indicated that design was a "new way of thinking", the instructors' approach did not reflect this enough. Instructors need to change their approach; however, it does not happen all of a sudden. In order to change the behaviours and the approach of the instructors, first their understanding and beliefs about creativity must be examined. This issue will be discussed in depth in Chapter Seven.

6.2 INSTRUCTORS' UNDERSTANDING AND BELIEFS ABOUT CREATIVITY

Creativity needs to be valued in an educational context to enhance it. This depends on the understanding of creativity practice. The instructors agreed on most of the areas that had been suggested during the Action Research. However, it was observed that they did not apply many of them thoroughly. The reason for this was that they did not value creativity enough – or at least didn't understand how to teach it appropriately. They did not value using creativity tools, making presentations, doing sketching, or giving feedback as key learning methods to promote creativity.

There was a conflict between what instructors said in meetings with other staff and did in practice in class. This situation was described by previous research: Kane, Sandretto, and Heath (2002) said that research based only on what university educators say about their practices without their being direct observations of what they actually do, has the risk of telling only half the story, and therefore, needs further research. Therefore, this section of the study looks at the phenomenon from a deeper level and presents findings that were not very explicit. Beliefs about creativity among staff and students was analysed. The effect of instructors' educational background on the creative process and their functionality mindset is examined. The impact of the subjective nature of creativity was questioned. The emphases on design product and product performance were examined. Each of these findings will be explored further in the following sections.

6.2.1 What do instructors and students believe about creativity?

The first step in the study was to clarify the understanding of creativity among instructors and students. The survey results done in two consecutive educational years showed that students' understanding of the key concepts of creativity harmonized with instructors' perspective. Among the given characteristics of creativity (See Appendix XIV), the majority indicated that "innovative" represents the characteristic of creativity or of a creative output. Then terms like "imaginative" and "functional" come respectively. Instructors defined creativity as "surprising" and "concerning novel ideas" (ME-I3), or "being all about various solutions, ingenious solutions, solutions that are not too obvious" (ME-I1). Student comments were similar: "Creativity is coming up with new ways of doing things, new approaches, new ideas that maybe haven't been done before. It's the process of finding ways that you can design different things" (ME-S4). It is "trying to find something that you can change to improve" (ME-S5). It is agreed that it's a part of engineering design and it is required (ME-S5, ME-S6, ME-S7). These arguments show that students' and instructors' understandings about creativity were alike.

Although there was a consensus in the understanding of creativity, the study shows that creativity was not highly valued in an engineering context. ME-I4 indicated to students that creativity was necessary in this unit, however, s/he stated that students were not "aware of it because they believe that creativity was not part of the realm of engineering […] ME students don't believe that they've got any idea of creativity". ME-I4 added that s/he worked as an engineer in the industry for a while and s/he did not think that people believed that engineers were creative: "I believe that people think that engineers are those technical people who take someone's idea and make it work. But there's no creative process in it, there's no innovation, there's no amazement, there's no beauty in it. I believe that as a society in general, we believe that creativity is exclusively linked to beautifying as opposed to creativity is linked to idea generation and innovation, not just the aesthetics of how something looks" (ME-I4). A student interviewee supported this comment by declaring that students were "more concerned with the performance than the aesthetics" (ME-S6). This quotation alone shows how participants relate creativity mostly with a product's appearance.

There was inconsistency in what instructors thought about when and where creativity was needed. The UC indicated to students in one of his/her e-mails to "get creative in the right areas" and warned them not to be creative in the areas which were already known and to use their energy wisely. The UC thought the students needed to know "when to be creative and when not to". It was reported by Mokhtar & Duesing (2008) that in a mechanical engineering design subject, students need creativity at some stages of the design project and in some stages, they do not need it at all. On the other hand, ME-I5 and ME-I1 contradicted this idea by stating that engineering students definitely needed to be creative all throughout their learning process and their career. "I think creativity is a process. So [they need to be creative] throughout the process of designing" (ME-I1). "They need to think about creativity as early as possible, they'll get the most out of it the earlier that they do it" (ME-I5). "You have creativity in framing the problem, creativity in generating ideas, creativity in selecting which one it is and then creativity in actually developing the one you've selected […] being able to balance all those trade-offs also requires some kind of creative thinking" (ME-I1). If instructors' approaches on creativity and creative thinking show contradictions, students would be confused. Therefore, consistency is needed among the teaching staff about when and where to get apply creative thinking in an educational exercise.

Another interesting finding was the misbelief of some instructors about students. Some instructors believed engineering students did not like doing presentations in front of others, or they might simply be introverts (UC). The instructors did not want to push the students to do presentations because they thought that students were reluctant to do presentations. The UC indicated that the students might be too introverted to do presentations in class. However, the survey results (Figure 6.1) showed that 38% of the students felt comfortable with doing presentations and liked to share their ideas, 53% of them felt neutral about it and said if they needed to do presentations they could do it. These findings enhance our understanding of student behaviour. The study argues that students' unwillingness to do presentations in class was dependent on the competitive assessment of the unit, not on their personal characteristics.

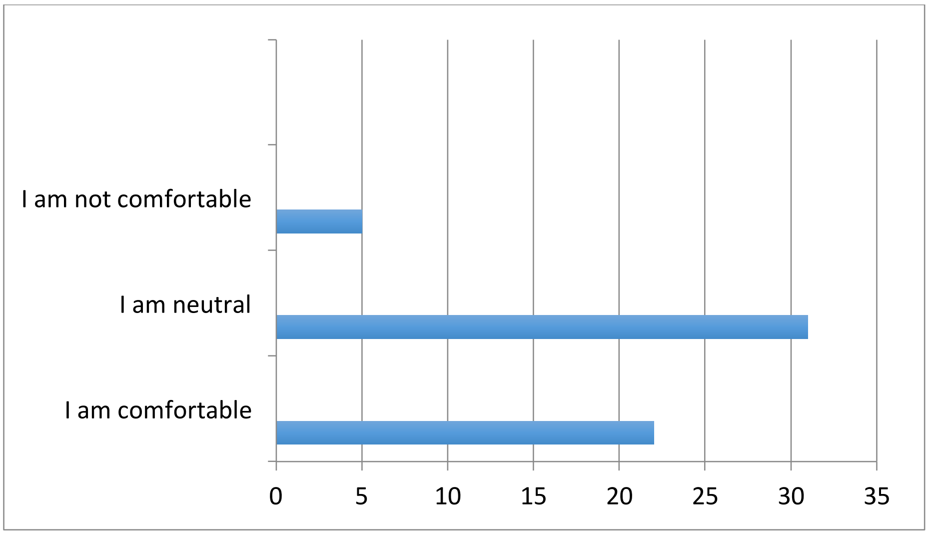

Figure 6.1 Student comments about doing presentations in class

Even though competitive environment motivated students it inhibited group discussion learning. Instructors assumed that the students thought that the others would steal their ideas (ME-I5, ME-I4). ME-I5 indicated that "part of it is personality, that some people are very introverted and some people really struggled with presenting and talking about their design. Part of it may be that they feel that other students were going to steal their designs". ME-I4 stated that "some people are petrified of anyone seeing or knowing what they're doing, because of the competition". Instructors believed that if the students thought that their ideas were good they hid them and did not want to share them with the others. Accordingly, they did not want to make presentations. ME-I4 said one team had a prototype, but they did not show it in class during their presentations. Although none of the students admitted that they were worried that the others would steal their ideas, instructors' observations made some sense, as the assessment of the works was performance based and one's success was dependent on others' failure. Undoubtedly a competitive environment prepares students for a real-life situation but it must not be forgotten that this is an educational context. Learning from peers is beneficial during the creative design process. Therefore, an environment must be provided for students where they can share their ideas without hesitation, and this should be facilitated by the instructors.

Students' and instructors' understanding of creativity align with each other, however, when it comes to creativity teaching practice in an educational context the instructors' approaches shows some variation.

6.2.2 How does an instructor's educational background affect their teaching?

The correlation between how instructors were educated and how they educate their students was interesting. Engineering instructors' earlier education affected their teaching approach. Most instructors admitted they had not practised creativity or creative thinking in class when they were students. They (ME-I5, ME-I3) claimed that they did not apply any creativity tools during problem-solving when they were studying engineering. They were not expected to give any presentations either. Because the instructors did not experience any application of creativity during their higher education process, they did not put much effort in applying any such methods in their teaching. A student admitted that s/he knew that they needed to do the design project in their own time (ME-S1). The instructors were asked about the design process routine when they were studying as students. ME-I5 and ME-I4 claimed that they were doing the design projects in their own time. Due to the instructors' similar educational backgrounds they see the current situation as completely normal and did not attempt to change it.

The instructors were asked about the assessment process back in their time as students. The UC declared that "we did creativity exercises to understand it but when it comes to actual assessment, we were never assessed based on creativity […] We were expected to come up with a number of ideas. But it was more of a performance assessment acknowledging the fact that you came up with a number of ideas" (UC). ME-I4 said that, "We were given a problem, and told to design something to fulfil the brief. If we won, we got full marks, it was graded down to who showed up with something that met the brief". Assessment was done for the end product, not the process (ME-I4). These previous experiences indicate why instructors preferred to focus on the final product rather than the process, as they were not educated that way either.

When instructors were asked when they had experienced creative thinking they said more while working in the industry rather than during their studies (UC, ME-I5). These instructors were working for the automotive industry and they both declared that they were expected to come up with a number of ideas for a problem while they were working. However, they admitted, while studying, that they were not given any marks for being creative, for keeping folios to record alternative ideas or for doing any presentations (ME-I4). The findings show that ME instructors' current educational approach is similar to the education they got. Instructors struggled in teaching creativity because they had not been educated that way themselves.

6.2.3 How does the subjective nature of creativity effect the instructor approach?

One of the main issues about creativity is its subjective nature. The biggest challenge that inhibited implementing creativity assessment in the engineering units was its subjective nature. Even though it was suggested making creativity a part of the rubric this was not applied in the first semester. When applied in the second semester, the final design products were not assessed according to creativity either. Creativity was officially expected in the assignments, in one of the exam questions and as a part in the final report. The instructors always marked the product performance, but not creativity, and they did not change the assessment way beforehand. The UC thought that "Students who are attracted to engineering like procedure, we have a lot of students who are accustomed to that. When you try to teach creativity to these kinds of students that can be emotionally confronting and sometimes traumatised, especially for students who've been getting good marks. All of a sudden, they confront a problem which has a subjective element, that's a huge shock for somebody whose identity is so strongly attached to marks and future success. That's the biggest problem we have".

The literature was full of many methods to assess creativity, which were mentioned in Chapter Two. However, it was challenging to convince engineering instructors to decide on a method for rewarding creativity. A couple of creativity assessment methods, claiming to lessen subjectivity (Treffinger et al., 2002; Cropley, 2015a), were presented to the UC. However, the UC did not agree to officially use either of them, because s/he thought the methods were still ambiguous. Even though CSDS (Cropley, 2015a) was used for assessing the creativity of the Solar-boats this was not reflected officially in the course rubric

The PDE rubric has descriptions like "a very good breadth of innovation/ideas" or "excellent breadth of innovation/ideas" for the product design process. The PDE rubric was shown to the UC, who was then asked about how to distinguish "a very good" design from "an excellent" design. The UC stated that it is "subjective" and added that "that's one of the challenges that we have (in ME). It is one of the things that has driven me towards performance based assessment [...] You can't argue with that (the current assessment method). Students can never argue with you about the marks" (UC). On the other hand, when PDE instructors were asked how they distinguish these levels when assessing, PDE-I3 hesitantly stated that "it's all subjective depending on the lecturer", but added that for an excellent creative product "one would not only come up with a good idea but they would have solved it and made it manufacturable for the real world. This is the difference between good and very good" (PDE-I3). PDE-I2 explained that they also used quantitative evaluation: "In the actual assessment rubric we actually specify it as new and novel designs. So, the students have to come up with a certain quantity of new and novel designs. We ask them to generate ten pages of concept sketches with four to six new and novel designs" (PDE-I2). The result of the study indicates that PDE instructors were more comfortable and confident then ME instructors in evaluating product creativity. ME instructors preferred standardisation in assessment, without human judgement, whereas PDE instructors did not hesitate to use their own judgement. A possible explanation for ME instructor behaviour is the ambiguous and subjective nature of creativity.

6.2.4 Are we valuing the design process as much as the product?

One of the underlying issues about the challenges of enhancing creativity is the excessive focus on the design product rather than on the design process. Engineering instructors did not value design and creative processes as much as the final product. Creativity was mentioned in the beginning of the semester by instructors as a part of the unit, however, it was not emphasised or brought up again during the semester. Evidence from student interviews support this argument: "We spoke about creativity I think in the first two tute sessions and since then, we haven't really discussed it an awful lot. Mostly in our tute sessions we just did tests. Creativity is not really something that we've gone into a great detail on" (MS-S4). Students were asked if creativity was encouraged by instructors. ME-S7 responded that "I didn't feel that they encourage creativity. We are not very much pushed to think differently". ME Instructor ME-I1 believed that the creative process led you to creative solutions. Even though instructors said that they valued the creative design process as much as the product, it was observed that their emphasis was always on the final product. This situation inhibited students' creative process experience.

Although all the instructors said that the design process was as important as the final product, they did not emphasize the importance of it in their classes. Therefore, engineering students focused more on the final design product. Talking about this issue, one interviewee said that the final product had more importance, “because it was a competition and we were trying to build something that would win the competition […] the end result was more important” (ME-S6). ME-S4 believed that “the process is probably a bit more important”, but s/he admitted that they haven’t thoroughly understood it as a group until the last week: “I think we were just so focused on getting the project finished that we might have sort of lost sight of the learning opportunities we could get from the process” (ME-S4). ME-S7, like his/her peer, admitted that they realised the importance of the design process after the term finished: “During, I felt it (the focus) was more on the product. We were stressed to make it done. Then after testing day, I realised that now the biggest part was the process”. Because the focus was always on the final product, this inhibited students from experiencing an effective creative process.

It can also be understood from the student reports that the students focused more on the product. The instructors declared that the winners of the Gear-box competition had written the worst reports. This shows that once those students won the competition that measured the product performance they did not put any effort into the reports for describing the process. They thought that they had already met the requirements of the unit. Students said they had become aware of the importance of the design process after finishing the class. Considering the fact that ME students had only two design units in a 4-year curricula, it is believed that clearly indicating the significance of the design process is necessary for their education. This can be done by asking them “to come up with a number of designs […] both diversity and quality of ideas” as ME-I5 indicated and to assess that process. Having design units where students are expected to build their projects each semester might also be helpful.

6.2.5 Does a performance/functionality mindset hinder creativity?

One significant issue is the relationship between product performance and product creativity. The findings show that the excessive focus on functionality and performance during the engineering design process trivialised and diminished the role of creativity. It can be said that, even though instructors believed the creative process was important, a full-performing functional final product was always the priority, no matter how innovative the idea was. As was said earlier, the students' priority was on the functionality too: "First we figured out the maths, ratios. We just first wanted to make something to work. Then we sort of pulled our creativity at the last stage to make it stranger, smaller, using less acrylic" (ME-S7).

In one of the tutorials, students explained a creative solution to the problem that they came up with to their instructors but in the end, they decided not to do this project because it was complex. When the students were asked why they did not go for that particular solution, their response was straight - They were sure that they were not going to be awarded for being creative or innovative so there was no need for extra effort. They said that only functionality was expected from them and there would not be any extra marks for creativity. This preference shows the ever-complicated compromise between a product function/performance, and its level of creativity.

Risk-taking is considered to be one of the pre-requisites for creative thinking. But, functionality and performance emphasis and 'you are an engineer' pressure coming from the instructors caused students not to take any risks. One of the student comments explains why they went for the simplest solutions without taking any risks: "If you try to keep it simple you decrease the chance of failure. Every complex item brings a chance of failure" (2015-MD-SWS). Students were asked if they thought about any alternatives to their designs. ME-S6 said that "there was a couple but we ended up going with the one that we thought was simplest and was the best as far as the scoring system goes" (ME-S6). They were asked if they pushed their ideas for creativity or not. The response was, "No we just went with what worked" (ME-S6). These comments show how students avoided risk taking while developing their ideas. Students thought that they only had to solve the problems set in the assignment with a full performing working product in order to meet the unit requirements. Although creativity was expected from all engineering students in ME design units it is argued that the current priority is on the product performance.

ME-I1 made an interesting explanation in the end that, simpler and common designs performed better and got higher marks. However, the creative ones were complicated, did not perform well and got low marks. This statement supports the students' preference for not taking any risks for creativity: “If there is a good mark for it (creativity), then everybody will know that this is all about creativity. But now it's just about performance, everybody all they want to do is perform the best, that's what it is” (ME-I1).

The study shows that the instructors’ emphasis was implicitly on the product performance. This belief shaped their behaviour and approach during the classes. This behaviour and approach was directly echoed by the students’ approach towards the design process. As a result, students were stressed that the product “has to work”. This mindset left creativity obscured behind functionality and performance. These findings lend support to the claim that the issue of excessive focus on performance during the engineering design process needs to be addressed if they are intent on enhancing the use of creativity in the design process. The product performance is integral to the success of the outcome; however, the level of creativity should not be compromised and should always be considered.

Enhancing creativity among engineering students is not possible until the engineering instructors understand and value creativity practice themselves in an educational context. However, the instructors also need to be supported by the discipline structure itself.

6.3 STRUCTURAL AND ORGANISATIONAL ISSUES WITHIN ENGINEERING

Enhancing creativity in these units being discussed not only depends on the educators, who are in the teaching position and to the students who are in the learning position, but also relies on the approach of the discipline or the university. No matter what or how the approach of the instructors is towards the teaching of creativity, if this position is not supported and valued by the discipline itself, their efforts and intentions will not be effective. The structure of the curriculum, the organisation of the units and the subjects must align with what is intended in terms of creativity enhancement in education.

This section outlines the issues around the current structure and the workload of the engineering design units, the approach of the discipline towards creativity and the current model of teaching.

6.3.1 Do the design unit structures promote creative thinking?

It was found that the current structure of the engineering design units did not promote creativity and creative thinking. Both student and instructor comments about MD supported this argument: There was a need for "better structure of the whole unit" (2015-MD-SFS), "better organisation of topics" (2015-MD-SFS) and "it needs more structure in terms of how it is being taught" (2015-MD-SFS). "The biggest issue is the way the lectures are structured" (2015-MD-SOS). "There are two very distinct parts to the subject. The first part, is skills related to being design engineers: Creativity tools, mathematical modelling, developing thinking strategies etc. On the other hand, there is also the discussion of machine elements and how they work. These are both worthy goals, but I think that the subject can't quite decide what it wants to focus on. Instead it is trying to do both and as a result, it's not doing either particularly well" (2015-MD-SOS). These arguments show that the MD unit needs to be restructured.

The study shows that the structural issues in the design units prevented students choosing more open-ended design problems. Most students preferred design problems that required less workload. MD offered 4 different problems, 3 of which demanded an increased effort and a longer time than the usual semester-length. It was observed that most of the students preferred the least open-ended problem (The Gear-box problem) due to this problem requiring less commitment and less work. PDE-S1 explained that the reason for his choice of the Gear-box project was that it was the easiest project in MD and they "didn't want a high workload". ME-S4 admitted that even though s/he felt excited about Ball-handling s/he "would have preferred to have done Gear-box if s/he had time again" because of "the work commitment" (ME-S4). PDE-S2 supported this idea by saying that even s/he wanted to do Ball-handling project in ME, he chose to do Gear-box because s/he thought it would take less time. ME-S6 stated that the Gear-box problem "was the easiest one" and "it was the only one that would have results done by the end of semester". Similarly, among five different design project options in MSD, the majority of the students chose the Solar boat project.

The study points out that even though students liked open-ended problems, they preferred to do the ones that required less workload, because, they did not want to commit longer time on projects than they had to. It is believed that, all the requirements of the projects, whether they are open ended or close ended, should be finalised within the semester. This issue can only be sorted out by restructuring the unit and reorganising the unit content, because the current unit structure does not promote creativity by not encouraging open ended problems.

6.3.2 Does the unit workload allow enough time for creativity?

One major finding was that the heavy workload of the design units prevented students experiencing fruitful design processes. Various student comments summarised this issue: “A lot of different skills were trying to be developed in this subject, which was too much in the space of a semester. I understand that they were trying to develop us in a wide range of skills but it didn't let me focus on one aspect and become good at that” (2015-MD-SFS). ME-I1 mentioned the issue of inadequacy of time in design units. With such little time, there was no time to be creative, just time to be efficient. The way the unit was designed is actually not helping creativity, but rather favouring efficiency (ME-I1). Some students suggested having more contact hours: “I would recommend more contact hours, I found it hard to keep up due to the amount of information and work with respect to the amount of time spent on it each week” (2015-MD-SFS). “The time of the tutorial hour should be longer” (2015-MD-SOS). Because the ME design tutorials were overloaded, there was not enough time to cover all the requirements of the unit. This left very little space for creativity sessions, creativity assignments or class discussions and presentations. As a result, creativity became an extra load to students. One student showed his/her neglect towards creativity by mentioning the workload of the unit and indicating, “creativity is the least of my concerns” (2015-MD-SWS). The data appears to suggest that students saw creativity as an additional thing, not something fundamental that was required for problem-solving.

The workload of the unit did not allow enough time for practising with creativity tools during the design process either. It was indicated a few times by the students that the overall workload of the unit and the time allocated to the design project within that workload did not match. Some students stated that they did not have time to apply creativity tools during the tutorials and one student suggested “to provide creative solutions online, not in tutorials or lecture, because that time is too valuable for actual problem-solving” (2015-MD-SWS). Another student indicated that “Creativity is an important quality in producing innovative and alternative designs, as well as fostering new approaches to completing tasks. There was far too much time spent on creativity that should have been spent going over mathematical modelling examples" (2015-MD-SFS), which were expected in the exam. These student views were backed up by the instructors as well. ME-I5 added that the structure of the tutorial hours did not allow them to spend enough time on the creativity tools. It was indicated to the instructors that it was necessary that the students practice creativity tools more than once to comprehensively learn them but ME-I4 mentioned the lack of time to do this properly.

ME-I1 summarised the issue of time: "If we think creativity should come into engineering design, then we have to create a system that allows it to be mainstream within what we want it to be. Otherwise it will just be another addition and students don't need additions, because they're already doing too many things in the units" (ME-I1). "Some of them they see creativity tools as being separate to how they are going to improve their design. And I'm not sure if many of them made the link between creativity will help you to come up with a really good design" (ME-I5). ME-I5 stated that "students seem so overwhelmed by the rest of the subject [which included tests, gearbox design, report, exam] and they "don't have enough time to think about creativity". ME-I1 admitted that s/he "struggled to find a balance between helping students to understand the contents, which are not the easiest mechanical contents to master, and reserving time for the creativity activities". ME-I4 indicated "there is a huge amount of information and learning that the students need to cover. Most students struggle with the amount they need to understand and need time to have input into both the core work and their projects. I felt the extra activities ate into the time the students had for their subject and after the introduction of the creativity that there was a feeling of 'do we have to' from the students […] I felt students spent so much time on all the extra deliverables that they never got into the project well". It is apparent that because the design units were already loaded, there was not enough time to embed creativity activities into an existing unit without compromising other content. Therefore, design units need to be restructured, as will be discussed in detail in Chapter Seven.

6.3.3 Does the discipline's approach encourage creativity?

In order to enhance creativity in engineering education, not only is the instructors' approach critical but the structure and approach of the discipline itself is also critical. The data shows us that creativity was not valued enough by the engineering discipline itself. Part of the reason for this is not allocating enough funding.

Assessing creativity required additional time. However, finding funding for the creativity assessment in ME design units was not possible. The creativity assessments of the final Solar-boat projects and creativity assignments were voluntarily done by the ME instructors. Additionally, the UC indicated (E-mail 19/10/2015) that "I have been asked to reduce sessional costs, and that means I can't get the tutors to do as much, another issue with teaching creativity". Not allocating sufficient funding for teaching creativity shows that creativity is not highly valued by the ME discipline.

The large number of students in the design tutorial classes was another issue. The instructor to student ratio did not encourage creativity in class. It was mentioned in Chapter Four that the student/instructor ratio was too high for having effective design discussions in class and following student progress. PDE design units had two instructors, whereas ME did not have that kind of funding for its tutorial sessions. ME-I1 reported that there was no time for second round checks in tutorials. S/he added that it was hard to hold the students in class while talking to all 20 students one-by-one in one hour. Student comments supported this issue: "The student/staff ratio is simply too high in the lectures for any good teaching to occur" (2015-MD-SOS). This was backed up by an instructor too. ME-I3 suggested that there should not be more than 18 students in a tutorial class. High student numbers in the tutorials (sometimes up to 25) made it hard for the instructors to follow each student's creative design process. Because of this, students did not have enough instructor feedback and not enough time to discuss their alternative ideas that might have had creative potential. Not allocating more than one instructor to a large tutorial group was another funding issue. This also revealed the discipline's approach to design units where creative thinking was expected.

Working in design units such as MSD and MD required a large workload. It was observed that even a 12-week period for participating in design units was barely enough. This was apparent from the act of the UC sending emails to students 3 or 4 weeks before the semester started. S/he introduced the unit and encouraged students to choose their design problem and to form their groups three weeks before the semester started. One of the students admitted "I was not in Melbourne yet when the lecturer started to send me a bunch of e-mails telling us what to do for it. It is too much to take in, especially to those new students" (2015-MD-SOS). It is apparent that the UC did not want to spend the early weeks of the semester on the introduction to the course but preferred to get in touch with students before the semester had even started. This action alone shows how loaded the units were. This is another organisational issue that needs to be considered.

After redesigning the MSD unit outline, the UC asked instructors in an e-mail: “We made the creativity section more specific to brainstorming and we demand that affinity analysis be used to show a diversity of ideas. There is however one remaining issue: What do we do with the rest of the content? With so much focus on the design project, how do we teach things like thermal systems, concurrent engineering, human actors, pressure vessels […] Some content might need to be moved to other subjects”. Apparently, there was not enough time to cover all the content and some of these topics needed to be covered in other units. When the units were loaded like this, it was not easy for the instructors to create room for creativity and creative thinking in their units.

Another aspect was the small number of units in the curriculum that included creative thinking in the curriculum anyway. Addressing creativity in only two design units in a four-year curriculum is not enough to enhance creativity in a discipline like engineering. Additionally, introducing design and creative thinking to students for the first time in their third-year unit was challenging. ME-I4 said “I think it (creative thinking) needs to be dealt with from the first day they (students) land here rather than waiting until they’ve been here for two years and then go right, there’s this. Design subjects for each semester. They just don’t have enough exposure to it. I think that design needs to be done from day one” (ME-I4). UC also believed having “design and build every semester” was the best way for teaching creativity in an engineering design context. Having only two design units in the entire curriculum prevented students having enough design experience. That in turn resulted in the students’ lack of exposure to the creative process. The study reveals that it is late to introduce the concept of creativity and creative thinking at third year level, because students have already formed their way of engineering thinking that is not easy to break. Based on the findings, it is argued that the engineering discipline in its practice does not actually value creativity or creative thinking.

6.3.4 Does the current model of teaching encourage creativity?

The current model of teaching will be analysed under two main points: The hierarchical relation among the teaching staff and the change in educational practices in the last twenty years.

The hierarchical relation among the teaching staff (lecturer and tutors) caused students to struggle in their decision-making process. The most striking result to emerge from the observations was that students took into consideration more what the UC said rather than the researcher or the tutors. Because the UC was giving the final marks the students paid more attention to what the UC said. Tutors did not have as much influence on the students as the UC did. It was also observed that students always tried to learn from the tutors what the UC valued more or how s/he preferred the reports to be submitted. It was observed that tutors could not encourage students to do presentations or to show their design works unless they were clearly and explicitly written in the unit outline or specifically indicated by the UC. This issue pointed to how the hierarchical structure of the teaching staff affected the students' learning process. No matter what tutors or the researcher told them about the benefits of creative thinking, if it was not valued enough by the UC the students did not value it either. This led to the students not taking into account the feedback that came from the tutors, which might otherwise have positively helped their development and understanding of the creative process. In an environment like this it was challenging for an outsider, in this case the author/researcher myself, to suggest anything to students.

Even if the tutors did not approve something about the unit structure, such as the marking of the reports (ME-I1), the final performance assessment (ME-I3) or the un-prescribed lessons (ME-I5), they did not have the authority to change anything. It was observed a couple of times in the tutorials that when students asked their instructors about something, such as changing the team forming rules, instructors said that it was the decision of the UC. For example, one of the instructors admitted that s/he did not like how the reports were assessed: “But the UC has his/her own reasons for it and s/he's the boss, so we go with it” (ME-I1). When this issue was raised, ME-I1 explained the situation: “There's always that conflict between as a tutor trying to tell students something and they feel that, oh no, no that's not what the rubric is saying”. One student complained about the inconsistency between the instructors: "[We need] better lecturer to tutor communication. So, the information they tell is consistent" (2015-MDS-SOS).

The change in education in the last 20 years made it hard to cover all aspects in detail. When instructors were asked about their engineering education when they were a student, ME-I4 stated that they had "40 contact hours a week in the first year and were expected to do 2 hours outside class per contact hour" (ME-I4). The UC said that the length of the semester was 13 weeks previously, not 12 as it currently was. It is apparent that the current education model, in which the contact hours of the units are minimised to cover the absolute necessary information in a course makes it hard to cover creativity in detail. The UC described the difference between the students of the past and present: "It is harder to be a student these days. At the past, we tend to work part-time, now we have students who work full time, their student identity is their second identity. They do not think 'I am an engineering student who works part time', they think 'I work and also I am an engineering student'" (UC). When ME-I4 compared the current engineering education to what s/he had 20 years ago s/he found that the part lacking now was "the hands-on experience": "There are only basic things are taught now, absolute minimum requirement every semester" (ME-I4). It was mentioned by ME-I3 and ME-I1 that students did not come to tutorials with theoretical knowledge to apply practically, so the tutors had to spend half of their tutorial time to repeat the lecture notes or to solve assignments. The UC also mentioned that the university supported an online and flexible education, and therefore some students did not come to lectures and missed some important theoretical knowledge. The study shows that instructors struggled to teach engineering components thoroughly with the current education system. This has resulted in compromising the teaching of creativity in engineering education. Based on all above-mentioned findings it is apparent that the current model of teaching does not encourage creativity.

6.4 CONCLUSION

The study aimed to enhance creativity and creative thinking of engineering students by focusing on two Mechanical Engineering design units. However, it was challenging to conduct some aspects of these aims during the Action Research process. The reasons were summarised under three categories: Engineering staff approach, beliefs about creativity and organisational and structural issues. The interpretations of these findings will be further discussed in Chapter Seven.

7 CHAPTER SEVEN: DISCUSSION AND CONCLUSION

"Creativity will be fulfilled only if it is valued within culture" (Runco, 2007, p. 371).

This thesis has thoroughly explored how creativity and creative thinking can be enhanced and taught in engineering education. The thesis initially examines creativity issues in the curriculum through qualitative studies and Action Research in two engineering design units. It clarifies the most effective approaches for teaching creativity in engineering curriculum with the aim of producing more creative engineers. In order to provide professional engineers who will be capable of meeting the requirements of the continuously changing engineering industry, it is important to enhance their education with further training in creativity.

During this research, the author came up with many suggested interventions and implementations to take action in the studied units for enhancing creativity among engineering students. However, not all of them could be applied as thoroughly as planned. A considerable amount of rejection had been expected from the engineering students towards the implementation of creativity techniques as these students had been taught more traditional engineering education. However, dealing with the reactions from instructors, dealing with their approach, their scepticism and resistance to the interventions was a surprising outcome of this study. Based on the evidence currently available, the overall finding of the study is interesting. It was more challenging to change the instructors' approach and the structure of the discipline for teaching creativity than it was enhancing creativity among engineering students.

Previous research shows that creativity and creative thinking are essential in the field of engineering and they need to be part of engineering education. However, enhancing creativity in engineering education is not that simple. There are many issues to consider, such as the curriculum, the unit structures, the academics' perspectives, the discipline's structure and approach, timing, budget issues, classroom configurations and/or the approach taken by senior leaders within an institution. The results of this study show that there are many challenges to overcome in enhancing creativity in engineering education at Swinburne University of Technology. There are three types of changes that need to be done in order to enhance creativity in engineering education, following Schein's (1984) diagram (Figure 3.2):

1. Changes in Belief: These changes comprise the understanding of creativity by the engineering instructors. Although it seems it might be hard to change the beliefs of the instructors, with relevant modifications in the structure of the units and with appropriate training it can be achieved.

2. Changes in Value: These changes involve the instructors' approach during the problem-solving process in the engineering design units. This study believes that if instructors value creativity more this will consequently affect students' understanding of creative processes in a positive way.

3. Changes in Artefact: These changes involve all the structural and organisational issues that need to be considered by the discipline/course itself.

During the Action Research process, the author, together with the Unit Convener and the tutors, tried to change some of the artefacts of the course such as implementing creativity sessions and assignments and embedding creativity in the rubric. However, this effort alone was not enough to enhance creativity. Even though the artefacts were modified, the values and the beliefs of the instructors about creativity did not change.

In order to apply the artefacts thoroughly we need to change the values of the staff. In order to change these values, we first need to change the beliefs of the instructors and the beliefs held within the discipline. Therefore, this study supports a holistic approach to delivering creativity in engineering education. Creativity must be valued by engineering educators, students and within the discipline itself. Thus, this research argues for the need of a holistic approach in delivering creativity in engineering education.

7.1 INSTRUCTORS SHOULD UNDERSTAND THE PRACTICE OF TEACHING CREATIVITY

Beliefs have an important role in instructors' teaching practices and in pedagogical decisions (Richardson, 1996; van Driel et al., 2007). There is a direct relation between instructors' beliefs and their practices (Henderson et al., 2011). Schein (1984) explains that in an organisational culture, members of the group should talk the same "language" in order to communicate. Therefore, it is important that all the instructors and other staff in the discipline are in agreement about teaching creativity. Then they can project this shared understanding to the students without any misinterpretations. Yerrick, Parke, and Nugent (1997) argue that if teaching staff examine their own beliefs about teaching and learning this influences their classroom practices in a positive way. van Driel at al. (2007) believe that in order to implement innovative methods in education, teachers' existing beliefs must be initially addressed. Henderson et al. (2011) reviewed almost two hundred journal articles about change strategies in STEM education and they claim that effective change strategy starts with finding ways of changing the beliefs of the individuals involved. However, as described by Cropley (2015b) many engineering staff and university administrators do not understand creativity enough to apply any change in the system.

The research shows that encouraging instructors to behave in a particular way or prescribing instructions about how to behave in class, as was done during the Action Research process, is not enough to convince and change the instructors' teaching approaches. Instructors first need to understand the practice of teaching creativity. Kazerounian and Foley (2007, p. 762) declared that "creativity is not valued in the contemporary engineering education", engineering instructors should initially understand the value of the practices for enhancing creativity. They should be open-minded, they should take risks and they should have motivation, interest and knowledge about creativity. If they continue to be conservative in their teaching approach, enhancing creativity in engineering education will continue to be a challenge.

When instructors see creativity as an extra aspect to the course, they will reflect this attitude onto their students. Accordingly, students do not see creativity as an essential part of the unit. Kazerounian and Foley (2007) support this argument by indicating that if educators encourage creativity the students will be more enthusiastic in learning about creativity. Likewise, Mitchell (1988) reported that engineering educators have some control over influencing learning about creativity; they have the freedom either to foster or discourage the creative development of the students. Therefore, this study argues that engineering instructors should first understand their roles as educators in enhancing creativity in engineering education.

Educational psychology research suggests that students' beliefs affect their learning and their class performances (Schommer-Aikins, 2004). A student's success depends on their attitudes as much as on their knowledge and skills (Besterfield-Sacre et al., 1997). Therefore, students need to change their beliefs and their approach to study methods for learning to think creatively. However, we cannot expect the students to understand the value of creativity unless their instructors understand the value of creativity.

Moore et al. (2015) explained the importance of engineering education staff's beliefs and their pedagogical approaches in shaping their teaching style, and how student learning is connected to changes in educators' teaching. Consequently, this section highlights the significance of the instructors' beliefs and perception about the subjective nature of creativity, how valuing the design process versus valuing the design product, the performance mindset and understanding the educational practices for creativity teaching.

7.1.1 Accepting subjective nature of creativity

Tolerance of ambiguity is a pre-requisite for creativity and is one of the characteristics of creative people (Piirto, 2010b; Sternberg, 2011; Sternberg & Lubart, 1996). The findings of the study are in agreement with the previous research and add that not only ambiguity but also subjectivity must be tolerated in creativity teaching.

It does not mean that creativity cannot be assessed because it cannot be measured by fundamental natural laws. Engineering instructors should understand that assessing creativity involves an amount of subjectivity, as creativity depends on human judgement. Even the researchers who suggest using a numeric approach for assessing creativity, such as Shah et al. (2000), consider the human aspect in the assessment process. For example, they (2000) suggest using the same cohort of people for the evaluations in order to minimise the human effect. In the same vein, Treffinger et al. (2002) suggest relying on human judgement when assessing the creativity of a design, as there is no absolute criterion for creativity.

The data yielded by this study provides strong evidence that a project that was creative for one might not be creative for another. This finding appears to suggest that having a design jury, made of experts such as lecturers, tutors, other students or other invited engineering staff, might be a good way to assess student works. Having a jury is believed to give a broader perspective in the creativity assessment, as it will not rely on just one instructor's judgement. The average of the marks given by each jury member can be considered for the final creativity mark. The author is not alone in this view; Williams et al. (2012) suggest having a panel made of specialists, such as a collection of instructors, for the assessment. Yuan and Lee (2013) indicated that their needs to be more than one creativity evaluator in a class for the evaluation to be reliable and valid. Another technique that decreases subjectivity is to use a set of shared assessment criteria. Christiaans (2002) argues that a valid and reliable way to assess the creativity involved in a product design process is using common criteria among the judges that overcome subjectivity.

Perception of creativity not only changes from person to person, it also depends on different contexts. The literature also highlights this situation. Something that is common in one culture could be uncommon and be perceived as creative in another culture (Cropley, 2015a). The UC also believed that creativity is "not only subjective but also contextual […] If you get everybody with a similar background, […] you can then start evaluating creativity more objectively" (UC). This comment justifies the argument for a jury of experts assessing the creativity of the works.

On the basis of the evidence currently available, it seems fair to suggest that ME instructors should first accept the subjective nature of creativity during assessment. Then, they should set up common assessment criteria and arrange for more than one assessor to be involved in order to reduce the influence of subjectivity.

7.1.2 Changing the performance mindset

One of the significant findings of the study is the impact of the instructors' performance mindset on the development of the students' creative processes. This observation has not previously been described by the literature. Although creativity is expected from all engineering students, it is argued that the priority given to performance in engineering design subjects inhibits the development of creative thinking. A functional full performing product that meets the needs and desires of the user is clearly of high priority. Designing functional, effective (Cropley 2015a) full performing products should undoubtedly be the core purpose of engineering disciplines. However, this must not deter creative input in design projects. Understanding the social, economic and environmental aspects of a product, while not compromising the products function, will ultimately ensure better quality products are produced.

These findings suggest that excessive focus on performance during the engineering design process needs to be addressed and room made in the process for fostering creativity. Providing some flexibility for students in a learning context and allowing them to think more freely is believed to release and encourage more creative thinking during the design process. The ability to create true innovation is much more difficult than ensuring effective product performance. As Cropley (2015a) indicated, an engineering product needs to be "novel" too, in addition to being "effective". Therefore, the study suggests that the emphasis on creativity needs to be increased in engineering design units. In order to do this, open-ended design problems that allow alternative solutions should be encouraged. This will enable students to better experience the iterative design process instead of the step-by-step progression that currently dominates the classroom experience. Students should also be motivated to focus on creating multiple solutions during their design process to find the optimum outcome, rather than just focusing on the most functional, the easiest and the common solution. As Piirto (2011, p. 29) indicated it is important "not focus on one solution too soon".

In general, it seems that the engineering instructors' focus needs to not only be on the product performance but also on the creativity and innovation involved in the development of the product. Only then, it is possible for the students to take risks in applying their creative thinking during problem-solving, which is essential for product innovation. The relationship between product performance and product innovation is interesting and has important implications for enhancing creativity in engineering. However, with such a small sample size the results need to be interpreted with caution. This is an important issue for future research.

7.1.3 Emphasising the design process

The study has gone some way towards enhancing our understanding of the teaching of creativity. The collected data shows that the design product is more valued than the design process in an engineering education context. The findings in this study also support previous research, which links the design process with enhancement of creativity. Wedelin and Adawi (2014) argue that completing a successful design process should be the requirement, rather than coming up correct final answers. This approach makes students relax and take more interest in the subject. Similarly, Adams and Turner (2008) highlight the importance of problem-solving as a "process" rather than just focusing on the "product".

Giving credit to the design process is believed to lead students to design a creative product. In order to increase the emphasis on the design process, assessment needs to be aligned with the desired purposes at all times. The generated ideas and the exhibited final outputs from the design process should both be considered in terms of their novelty and creativity. This will ensure students do not solely work with a functionality and performance mindset, but also add elements of innovation to their work process.

It takes time to develop creative ideas into innovative outcomes with commercial potential. Failure is a part of learning within engineering design education. Instructors need to understand this when assigning project tasks and assessment rubrics. This study highlights the necessity of encouraging the engineering students to learn from their design process rather than just focusing on their final product.

7.1.4 Understanding the educational context

Another surprising finding is the engineering instructors' expectations of their students. The study shows that the instructors' approach of "you are an engineer, and engineers have to solve everything" puts a pressure on students. It is therefore likely that there is a connection between the instructors' expectations and the students' approach to risk-taking.

It was observed that when students are expected to behave like novice engineers they hesitate to take risks to avoid making any mistakes. Secondly, this approach creates conflict when instructors try to give students feedback during the design process. The instructors encourage the students to make all the decisions by themselves, without any guidance. Then, when the instructors try to give the students feedback during regular consultation sessions the students are not willing to accept any feedback from their tutors because the students are not accustomed to getting any guidance from anyone before. There are however, other explanations. The aim of the instructors is undoubtedly to prepare students for the industry and real-life conditions, as they will graduate in a year or so. However, the instructors should not forget that they are still in an education context and students should have the right to fail during the learning process, which should not necessarily correlate to a failed grade. The process should be assessed more than the final outcome while the students are learning. The ME instructors should understand the difference between an educational and a professional context. Preparing students for professional life should not necessarily include expecting them to make all decisions by themselves without getting any support.

When discussing the educator approaches, educators' level of experience is another affecting factor. Fuller (1969) conducted interviews and surveys in different schools with student teachers and teachers to find out the concerns of the teachers about teaching and learning. He interestingly found that most of the inexperienced teachers were concerned about self-adequacy rather than methods of teaching or student understanding. On the other hand, experienced teachers were more interested in the success of students. In this study, the ME instructors had moderate teaching experience, therefore an accurate argument cannot be claimed according to their experience.

7.1.5 Risk taking and being motivational

Creativity explicitly reveals itself during the design process through risk taking and motivation. It was mentioned earlier that the instructors' 'performance mindset' and the 'you are an engineer' approach will not motivate students to be creative and will cause students not to take any risks. However, motivation and risk taking are the main pre-requisites for creative thinking. The importance of motivation is emphasised many times in creativity literature (Adams & Turner, 2008; Amabile, 1998; Cropley & Cropley, 2010b; Lin, 2011; Sternberg, 2006). de Bono (1993) directly links motivation with creativity. Felder (2006) adds that the traditional teaching model used in engineering education is not sufficient to provide motivation to students. Prior studies

(Piirto, 2011; Sahlberg, 2009; Sternberg, 2007) have noted the importance of risk taking in creativity.

The available evidence seems to suggest that engineering instructors are not risk takers, as they hesitate to try new approaches in education. Whereas creativity is all about risk taking. Enhancing creativity in education requires risk taking too. The current findings add to a growing body of literature on risk taking in education. Sahlberg (2009, p. 343) declares that educators must be able to take risks when teaching, because “there is no innovation without risk-taking”. ME-I1 declared “in engineering there's always a formula, there's always a route to follow. Being able to see beyond the traditional way of doing things, that's creativity” (ME-I1). This quotation alone means enhancing creativity in education also requires a creative approach, which is possible through risk taking. It seems fair to suggest that instructors should not depend on strict routes in their teaching approach. If engineering educators avoid taking risks in their teaching, there is little chance that they will achieve their aims in outcomes.

The literature is full of researchers and educators describing their experiences in applying different methods to enhance creativity in engineering education. The results are usually positive, which means creativity is generally promoted and recommended to be increased. Most of the researchers who carried out these studies already had interest and motivation in the teaching of creativity. However, this study chose random instructors to work with who did not have any particular interest in teaching of creativity, except for the UC. Not all of them were particularly interested in creativity, but when they were asked they did accept to participate in this study. This supports the idea that in order to enhance creativity in an educational context, not only the students but also the educators must be motivated to enhance creativity in the course. The instructors themselves need to be motivated toward this end in order to encourage their students to be motivational about creativity. Only if educators are motivated can they modify their beliefs and values about creativity in engineering education.

7.2 INSTRUCTORS NEED TO VALUE CREATIVITY AS AN IMPORTANT PART OF ENGINEERING DESIGN

One of the most significant findings to emerge from this study is that teaching creativity to engineering students is not possible until the engineering instructors value creativity as an important part of engineering design. The literature has already mentioned the effects of clear communication between the engineering instructors and students on developing students' creative skills. (Daly et al., 2014). Engineering educators should be the role model for creativity. They need to demonstrate that they understand creativity, why it is important and why it is in the curriculum (Cropley, 2015a; Sternberg, 2007). Lim et al. (2014) support the idea that the staff should introduce a clear vision of the role of creativity in engineering in the units.

The instructors' approach has a significant impact in fostering creativity in class. The educators need to know how to guide and motivate the students during the design process, how to conduct creativity sessions, how to prepare an environment for creativity to be encouraged, how to give valuable feedback and how to assess creativity in the process. In other words, the instructor is required to know how to conduct a design unit for better creative student outputs. This is only possible if the instructors understand the practice of creativity themselves and the role of being an educator.

In order to encourage students to apply creativity, instructors need to understand how and when students get motivated. Just saying "be creative" to students does not necessarily encourage them to be so. Students need to first make connections between creativity and engineering. They need to understand 'why' they need to be creative before 'how' to be creative. Then, they can be taught the benefits of using creativity tools, doing presentations or sketching as part of their creative process. If students do not value creativity, they do not value the things that would help creative thinking. However, the first link in the chain is the instructors. First, the instructors should value creativity so that the students do too.

7.2.1 Creativity tools

Torrance (1977), one of the pioneers in creativity in education, highlighted the importance of providing adequate warm-ups for creative thinking by "mind-stretching" activities. The study showed that most of the engineering instructors did not value creativity sessions enough when they were introduced in the first weeks of the problem-solving process. This caused students to not gain enough benefit from this initial phase of the design process.

The aim of conducting creativity exercises is to encourage students to look at the problem from different perspectives. This is significantly effective in providing a discussion environment that stimulates creativity and gets all the students involved. The creativity tools should help to reframe the existing problems, and they should be enjoyable for both the students and the instructors. However, just introducing some creativity tools and encouraging students to use them is not enough. The study suggests that educators should value using such kinds of tools and should show how to apply them during problem-solving sessions.

The study produced results which support the previous work in this field. West et al. (2012) argue that the aim must be helping students become more creative; not teaching them creative methods of problem-solving. Some researchers (de Vere, 2009; Nepal, 2013) note that only giving problem based learning exercises to engineering students is insufficient for developing their creative skills. Students need to learn how to apply their knowledge, and this requires experience. Therefore, the study argues that the application of creativity tools should be linked with the design problems as a phase in the design process. Alternatively, providing some open-ended problems (in quizzes or exams) might help students to gain practise in using these tools; however, it is not enough to understand the benefit of them. Students should accept creativity as a core part of their design process, not as an extra concept in an exam question. The students should use these types of creativity tools in their design process. This is something that needs to be developed in ME design units, as PDE students already have this habitually. This is only possible if instructors give enough value to applying creativity tools; facilitating creativity sessions in class and encouraging students to use creativity tools. As Welkener (2013) suggested, educators should show students how to be creative by modelling it.

One of the major findings was the significance of the timing these kinds of tools were first introduced to students. It was observed in the PDE context that when students were encouraged to learn creative thinking skills in the initial year of their higher education, they used these skills in the following years. de Bono (1990) supports this argument by associating creativity with muscle building; people need to practise creativity to become more skilled in creativity, much like strengthening muscles. Experiencing creativity tools should not be delayed until the 3rd or 4th of year of the curriculum. The solution is to introduce creative thinking tools to students as early as possible in their education. It is believed that if students practise a few creative methods that align with the objectives of the unit their creative thinking would be enhanced in following years. This argument is aligned with the previous research. Felder and Silverman (1988) suggest integrating creativity methods as thoroughly as possible into the engineering curriculum.

7.2.2 Guiding students

For enhancing creativity and developing creative ideas, problem definition and idea generation processes are the essential initial stages of the design process. The data appears to suggest that instructors did not value giving guidance enough to the students during these processes. As a result of this students struggled both in their design process and in their time management. This caused limited focus on the creative process. Considering this cause and effect situation the study argues that engineering students need to be guided throughout their problem-solving process to experience an effective creative process.

Giving regular feedback to students provides a safe environment where students can ask questions and be involved in discussions about the creativity of their concepts. These findings confirm what Cropley (2015a) suggested: that “creativity can be fostered and developed through specific activities and with appropriate guidance” (p. 231). According to a survey done with graduate mechanical engineers from a New Zealand university, “personal supervision” was found to be a more valuable teaching method than “lectures and tutorials” (Deans, 1999).

As the literature recommends, breaking the design tasks into little phases and addressing these steps every week (Valentine, 2012) would help students to gain experience in creative and design processes. Engineers mostly deal with pragmatic problem-solving, where they develop known solutions (de Vere et al., 2010b) and their ability of defining and solving open-ended problems are not very developed (Dick, 1985). A closer look at the study indicates that students should be guided during problem-solving. Instructors should not forget the fact that if students are confronted with the design process for the first time during their higher education life, this would be different than what they are used to in other traditional engineering units. Therefore, it is especially important to support engineering students in their first design process. This would help them to manage their time and to allocate enough time for the 'front-end' creative process.

The relevance of guiding students in a creative process is clearly supported by the previous research. Zhou (2012b) believes a positive attitude toward creativity helps individuals engage in creative efforts. Daly et al. (2014) suggest that instructors could give more feedback to their students. Hmelo-Silver (2004) underlines the role of the facilitator in a Problem/Project based learning environment. Another suggestion from the literature is conducting design critiques, described by Goldschmidt et al. (2014) as the "bread and butter" of the studio activities. These design critiques play an important role in the development of students' creative thinking. In short, this study has shown that in order to enhance creativity, engineering instructors should value guiding students during the design process.

7.2.3 Presentations and Sketching

This research has shown that engineering instructors did not value presentations and sketching sessions enough. These are important parts of the design process, which are essential in helping students develop their creativity skills. Trevelyan (2010) described the benefits of presentations in engineering. Likewise, the importance and necessity of sketching are highlighted in engineering (Cross, 2008) for the design process, and for developing creativity (de Vere, 2013). Sketching helps not only to communicate easily with others, but also helps the person to develop new ideas (Dick, 1985). However, many Mechanical Engineering programs do not teach enough sketching (Zemke & Zemke, 2013).

If the instructors believe a particular method is good in terms of enhancing creativity, such as doing presentations or keeping a design folio, they should do more than just mentioning them in class. Educators should provide a trustful environment for the students to express themselves. The study illustrates that engineering faculties should concentrate on the above-mentioned skills and train their students accordingly. On these grounds, it is argued that engineering instructors should focus on developing students' verbal and visual communication skills by valuing presentations and sketching, in addition to valuing their technical knowledge. This is possible by creating an environment where students can be encouraged to do presentations, to share their ideas freely and to sketch.

7.2.4 Rewarding creativity

The relevance of assessing creativity is clearly supported by the current findings. It was described in Chapter Five that the assessment of the creativity involved in the development of a product was not practised in the units as planned. Most of the students did not participate in the assessment, because the instructors did not value creativity assessment enough. Hanrahan and Isaacs (2001) highlighted this issue too; If the assessments are not reflected in the final grades neither the assessors nor the recipients take them seriously. This result explains the good correlation between motivation and the assessment for creativity. The study explains that the assessment of the involvement of creativity in the development of the product must be reflected in the final marks, as "assessment plays an important role in students' motivation to learn" (Daly et al., 2014, p. 434).

If there is no assessment or encouragement for creativity in the projects offered, then the outcomes will rarely deliver this. It is argued that all engineering design projects should have an embedded assessment for creativity, which will at least 'force' the students to develop creativity. Assessing not only the performance of the final product but also the creativity of the design will encourage and motivate students to undertake better creative thinking processes.

It can be said that the importance of creativity was acknowledged by the ME instructors, but not enough in an educational context. Therefore, the students did not comprehensively understand the value of it. Instructors expected students to generate creative ideas and to come up with innovative solutions. However, this was still treated as an addition to the product performance rather than assessed with equal importance. Therefore, students assumed that creativity was optional and they did not value it enough.

Another factor that negatively affected the assessment process was the ambiguous nature of creativity. Engineering instructors did not have any experience in assessing the creativity of design products. Until that time, they had always assessed the performance of the products, depending on a particular formula. Mitchell (1998) emphasises the difficulty of defining and accordingly judging creativity. Therefore, engineering educators should do their own version of a definition of creativity that suits the process involved in the design unit. (Mitchell, 1998). Cropley (2015a) backs up this argument by suggesting to set up an assessment plan for the creativity of design works, defining what is actually creative and what is not in that context. Then an appropriate pedagogy can be constructed around this. On these grounds, the study suggests that engineering instructors should come up with their own definition of creativity in their units and an assessment plan for rewarding this version of creativity. Then students could interpret what type of project submissions would get a good mark and what type of submissions would fail in terms of the creativity and innovation of their designs. These findings further support the idea of Takai (2011), suggesting that instructors need to assess student works with both a creativity and a performance assessment in order to motivate their students to embody creative ideas.

7.2.5 Peer evaluation

The study showed us that seeing their peers' work gave the students more drive. However, ME students did not often have the chance to see their peers' work. One possible explanation for this is that instructors did not value peer assessment enough. So, the structure of the unit did not allow enough time and space for students to do peer evaluation. I put forward the claim that if students were provided with an environment in which they could see others designs and could observe each other's' design processes, this would give students more motivation for developing creativity, as it happens in a PDE context. If students had a chance to assess their peers, it would have been very helpful for them in learning not only from themselves but from their peers too.

Previous research (Pappas, 2002) supports this result by suggesting getting feedback from both the staff and the students for effective design teaching. Kim, Jin and Lee (2009) argue that the more the designers draw on external knowledge the more original and unique are their design solution results. Therefore, getting as much feedback as possible from peers and instructors are vital. As Falchikov (2003) described, clear instructions must be given to students relating to all stages of the design process in preparing students for a self and peer evaluation process. The creativity criteria must be provided for discussion with their teachers so that they can understand what is expected. Finally, an assessment plan should be created that puts students in the centre, so they can better own their learning (Falchikov, 2003).

Taken together, these results suggest that peer assessment needs to be part of the creativity assessment process in design units, as it allows learning from others and develops self-evaluation skills.

7.3 THE DISCIPLINE NEEDS TO VALUE CREATIVITY AS A CORE PART OF THE CURRICULUM

In order to enhance the development of creativity in engineering education, creativity first needs to be valued by the discipline and be included as a part of the curriculum. Only then would it be valued by the instructors and by the students. Promoting creativity in engineering is not possible until the discipline cooperates. This study builds its argument based on previous research. McMasters and Ford (1990) suggest that the university needs to change its approach to fully integrate design teaching into the curriculum. To stimulate creativity development in learning, the curriculum has to be flexible (Craft, 2003). However, this is not easy. Any kind of change in academia requires a big effort because structures and traditions need to be broken (Berglund et al., 2011). This should also align with the school's tradition whether it is more design or innovation based as stated in Klinker and Alexis (2009).

Foley (2014) mentions the difficulties of developing new curricula in engineering, because adding something new might lead to removing other valuable content. However, by using effective teaching and learning tools, new content can be complementary, not competitive (Foley, 2014). Henderson et al. (2011) highlight the requirement of understanding the complex system of the university for making a change and developing a change strategy. This study is in agreement with Henderson et al.'s (2011) argument that the main barriers to teaching creativity are the beliefs of staff and the structures of the institutions.

This study acknowledges the fact that if change is not supported by the discipline, it is not easy for the instructors to enhance creativity in engineering education by themselves. Briefly, this section discusses the requirements that need to be done by the discipline for valuing creativity as a core part of the curriculum.

It highlights

- restructuring the design units,

- allowing enough time and budget for the design process,

- training staff for teaching design and creativity,

- starting the teaching of creativity process early in the curriculum,

- and the benefits of having design units every semester.

Having said this, the reasons for change need to align with course advisory panels and new expectations from industry. The purpose of educating students in engineering is to provide professional skills that are useful to industry. With industry forever changing and adapting to new technologies and materials, highly relevant to engineering, universities need to change with it. And not at the same pace but rather at a quicker more advanced pace. Universities should set the knowledge agenda and inform industry of the latest technologies and materials to help continually advance the discipline. Without this and without the focus on creativity in engineering the discipline will be at risk of becoming stagnant and will not meet the needs of an advanced society.

7.3.1 Restructuring the design units

Analysis of the results show the following: In order to enhance creativity, to focus more on the design process, to integrate the creativity requirements in the unit outlines and to make creativity part of the assessment, design units need to be re-structured.

The data gathered in this study, such as the findings of Anderson (2013) suggests that there is not enough space and time to integrate creativity into existing units because they are already loaded with technical content. So fulfilling all the requirements of the units becomes a big issue time wise. Because of this situation, creativity was perceived as an extra expectation in the unit. Therefore, the design units need to be reorganised to fully integrate creativity expectation into the design process. Otherwise, creativity will continue to be an additional aspect in engineering design units.

One of the significant findings of the study was the need to shift the emphasis from holding an exam in the design units to assessing the practical process of the design projects. This would to allow students to focus more on the design problem in class and experience a more efficient creative process. As a result, the study argues that exams should be removed and alternative methods to examination must be considered to assess student knowledge in design units. If the exams are valued more than the design projects in design units, students will not understand the value of a creative design process. This argument is in agreement with Berglund et al.'s (1998) findings, which show that traditional types of examinations are not developing students' creativity. Sahlberg (2009) sees test-based accountability as a barrier to creativity too.

Another major finding was the necessity of making creativity a part of the rubric and explicitly identifying creativity to the students as part of the learning objectives. If creativity and creative thinking expectations from the students do not become formal requirements of the unit, and not assessed, enhancing creativity is not likely to happen. Therefore, the expectations for learning creativity must be expressed in formal unit requirements. The unit outlines must be reorganised and restructured to include aspects of creativity, thus both the students and the tutors would know what is required. This needs to be done to show expectations of creativity development as part of the unit. Torrance (1977) states that to enhance creative thinking it must be made clear that this is expected and will be rewarded. Without addressing these points, it is not easy to enhance creativity in engineering education with the current structure of the engineering design units. The findings of the study also support previous research which looks at the value of encouragement: "In an engineering design course where creativity is a learning objective, students must know that creativity is encouraged and supported. This encouragement and support should align with course assessment, and instruction, discussion, and feedback should help students figure out when and how to explore creative options" (Tolbert & Daly, 2013, p. 889).

The benefits and relevance of the aforementioned facts in previous sections such as sketching, doing presentations, getting regular feedback and assessing peers should be clearly indicated to students. They should also be embedded in the unit structure. If all these expectations from the students become formal requirements of the units, it is believed that students will benefit more from them in terms of creativity.

7.3.2 Allowing enough time and funding for the design process

The most obvious finding emerging from this study is the inadequate time and funding for integrating creativity in the design units. An implication of this is the possibility of re-organising the tutorials to allow enough time for giving feedback, applying creativity tools, doing presentations and assessing the creativity involved in the students' design works. The literature confirms the findings that the design process evolves around iterations and repetitions (Atman et al., 1999). Time must be allowed for the creative process, as it occurs in a cycle of stages (Sternberg, 2007; Runco, 2007). Therefore, the design units should be modified in a way to allow enough time for a creative design process to go through that cycle.

The concerns around curriculum compaction had always been an issue and was covered by many early hallmark reports on engineering education too. With the advancements in science, the number of engineering subjects increased and time schedule started to be become an issue. Mann report (1918) highlights the necessity of compacting the subjects in consistent programs and specialisations in engineering. The Grinter report published in 1955 describes the necessity of new concepts and shifts in engineering curriculum influenced by the continuous increase of new scientific and technological knowledge. Although the report first suggests several additions to curricula without any deletions, the Committee on Evaluation of Engineering Education of the American Society for Engineering Education feels that the most reasonable way of finding time for new content is to eliminate some present material (Harris et al., 1994).

It is believed that if the discipline and instructors valued the design process enough time would be allocated, not only for the creativity process within the design units as they exist now, but also within the whole 4-year curriculum. Youssef and Kabo (2015), who did a similar study in a Machine Design unit, argue that allowing enough time in the initial steps of the design process will shorten the overall project time and will result with more efficient final products that meet all the required design criteria. The UC indicated that design takes a longer time than the other units of engineering, but this also needs to be understood by all the staff (UC).

Another important point that emerged from the study is the need to allocate enough funding for promoting creativity. First of all, it is needed for assessment. Because evaluating product creativity and the design folios require additional time, instructors must be paid for this time and effort in order for them to assess everything effectively. Another aspect that needs funding is organising design jury duties – especially during the final presentations. It is believed to be beneficial for students that more than one instructor be employed for assessing student works for creativity. As previously mentioned, this method decreases the problem of subjective human judgement in assessing creativity by taking the average of the different assessors' marks. Allocating more instructors to design tutorials is another suggestion of the study, because the results showed that the instructor to student ratio in the tutorials was insufficient. The research study by Hmelo-Silver (2004) also found that excess number of students in a classroom for one facilitator is a barrier to creativity. However, without funding, these above-mentioned recommendations cannot be realised. Therefore, the discipline should allow enough funding for enhancing creativity in design units specifically and in the engineering course generally.

7.3.3 Staff training

The study showed that the instructors were not experienced in facilitating creativity sessions. Depending on the findings, the research proposes that the instructors should be trained to facilitate creativity sessions and they should be equipped to assess creativity in design works. The study produced results that substantiate the findings of a great deal of the previous work in this field (Felder, 1987; Liu & Schonwetter, 2004; Mitchell, 1998), which indicates that the educators are responsible for preparing groundwork for creative opportunities. Even though the instructors play a crucial role in transmitting knowledge of engineering they are not trained pedagogically, so their effectiveness depends on their "experience, awareness and talent" (Goldschmidt et al., 2010, p. 285). One of the barriers to Problem/Practice Based Learning (PBL) is a lack of experienced and skilled facilitators (Hmelo-Silver, 2004). Daly et al. (2014) suggest that if engineering instructors can communicate clearly with their students about the learning goals of the subjects they can support developing their creative skills.

Taken together, the findings of this study recommend that engineering educators should be equipped and trained about how to deliver teaching of creativity in order to be more effective in teaching design units. This is only possible if the discipline values and prioritises staff training programs for enhancing creativity in engineering.

7.3.4 Starting early in the curriculum

A closer look at the data indicates that the best way for the engineering students to get familiar with the design process is to teach them design in the early years of their education. Torrance (1977), when speaking of teaching creativity to 'children', indicated that it should be done before their higher education. This shows that students must be encouraged in developing creative thinking even before they come to the university. Therefore, the results of this study suggest considering the creativity issue in higher education from a holistic perspective and promoting it as early as possible in the curriculum. If we expect our students to become innovators in the workplace, this will not happen without first giving them the seeds of creativity. We cannot expect graduate engineers to think creatively all of a sudden when they start working, unless they were exposed to creativity at university.

If using creativity tools had been taught to ME students in their first year, as it was taught to their peers from PDE, they might have gone to 3rd and 4th year design classes more equipped and could have directly applied the tools to given design problems. Otherwise, when students come to the final year of their education it is not easy for them to change their performance oriented traditional mindset. Similar to what this study found, Pappas (2004) warns that engineering students might show resistance to studying different thinking skills due to the fear of being in new and unfamiliar territory. Therefore, different thinking skills should be introduced before this prejudice can be established. The findings support what Youssef and Kabo (2015) found when redesigning the Machine Design unit in a USA university to promote creativity. The reason for the lack of ideation among students was the lack of exposure to design units earlier in the course. The focus had always been on technical units, with no emphasis on the design process and its applications (Youssef & Kabo, 2015).

On these grounds, it seems that an introductory design and innovation unit will be beneficial for enhancing creativity. Cropley (2015b), who is a specialist in promoting creativity in engineering education, agrees with this argument. CDIO (2016) also suggests an "Introduction to Engineering" subject in the curriculum that will provide the basic framework for engineering practise by exposing students to problem-solving. The present study confirms previous findings and contributes additional evidence that creativity needs to be integrated in the engineering curriculum, starting from the first year. However, the best solution might be to have a design unit in every semester if the curriculum allows.

7.3.5 Design unit every semester

There is overwhelming evidence supporting the notion that it is not possible to enhance creativity in a limited period such as in one semester. The study showed that enhancing creativity in students in just two design units in a 4-year curriculum is challenging. Although engineering education is full with technical subjects, design and innovation skills cannot be taught in a single semester. The findings of this study are consistent with the previous research. As Cropley and Cropley (2000) indicated, a few subjects are not enough to fully develop the creative potential of the students. Lim et al. (2014) support this idea by suggesting a holistic approach in developing creativity by systematically redesigning the whole curriculum. Crawley et al. (2011) add that creativity in engineering education needs to be addressed at the curriculum level rather than just at the course level.

It is argued that a design subject each semester would not only encourage engineering students to develop their design skills, but would also better increase their creative abilities throughout their whole degree and beyond. The unit convener of the ME design units agrees that the most important ingredient in increasing the level of creativity in students is a "design and build approach", and suggests having it every semester (UC). If students are regularly and frequently exposed to design, they will eventually learn that they need to look for innovative solutions, start the design process early, be prepared, take advantage of tutor guidance and benefit from the peer feedback and the presentation sessions. These will support them to be the future creative thinkers in the engineering field in the 21st Century.

The findings of the study are in agreement with Anderson's (2013, p. 4) results: Design and creativity skills must be distributed through the curriculum and not be limited to a couple of classes. However, it is not easy to design an accredited engineering program including all of these aspects (Anderson, 2013). Other researchers also indicated the challenge of structuring an engineering program with integrated creativity training (Morin et al., 2014). Lim et al. (2014) argue that just engaging students in a creative environment and applying creativity tools is limited in developing creativity in students; we also need to integrate these tools wisely in the curriculum. Due to the large number of topics to be covered, design projects should ideally be integrated into the whole curriculum and be an integral part of both technical and non-technical courses (Moore & Voltmer, 2003). CDIO (2010) supports this by suggesting having at least two design experiences in the engineering curriculum, ideally one at a basic level and the other at an advanced level. However, accepting that creativity is inherently linked to design, does not mean that embedding more design subjects in the engineering curriculum will automatically increase creativity. By all means, in the presence of more design subjects, students will be exposed to more open-ended problems and do more practice – learning by doing.

All of the changes that were mentioned in this section can be applied, but only if the discipline values creativity as a core part of the engineering curriculum. This action is believed to also shift the instructors' approach, which will be reflected in their teaching style in class. Accordingly, students will get a benefit from this shift.

7.4 CONCLUSION

The present study was designed to explore ways of enhancing creativity and creative thinking in engineering education to promote innovation. These findings increased our understanding of the barriers to teaching of creativity in engineering education. The study suggests that in general, enhancing creativity in engineering is challenging. The important aspects in order to teach creativity and creative thinking in engineering education in an effective and efficient way are summarised under three main points:

- Instructors should understand the practise of creativity in an educational context.

- Instructors need to value creativity as an important part of engineering design.
- The Engineering Discipline needs to value creativity as a core part of the curriculum.

Engineering instructors' understanding of creativity practises in an educational context needs to change. They need to adopt a particular approach when teaching creativity throughout the design process to help promote innovation. It is most important that the instructors should value creativity and creative thinking as important aspects of engineering education. However, this alone is not enough. Instructors must be supported by the discipline, meaning the engineering discipline needs to value creativity too.

If engineering instructors do not change their approach and the discipline does not cooperate, enhancing creativity in engineering education seems not likely to happen. In this case, as de Bono (1993) suggested earlier, creativity needs to be taught to engineering students separately by creativity specialists. Finding time for it in the curriculum would still be an issue to consider. Even if creativity is learned separately, if it is not promoted, expected, assessed or supported in other units, this will not be beneficial either.

Applying any change to an already working structure needs a big effort, especially if this structure is in academia where the participants are all specialists in their field. The held beliefs and traditions need to be broken down and modified. Anybody who attempts doing this will undoubtedly face challenges and resistance from the educators and the discipline. Therefore, if creativity is going to be enhanced in engineering education, the educational researchers, the curriculum developers and designers should study this issue along with the engineering educators. They all need to work collaboratively and excessively hard to identify the underlying barriers to teaching creativity and to overcome these barriers. Otherwise, if we just look at the symptoms and write prescriptions for them we will not fix the real underlying reasons but just treat the symptoms. However, our aim must be to examine and to be aware of the barriers to enhancing and teaching creativity in engineering education. Only then can a more structured teaching plan be developed for future studies. This challenge needs an interdisciplinary study. Undergraduate engineering students need to be equipped with creative thinking skills that lead to innovative solutions in addition to conventional problem-solving skills. This will not be possible unless we educate our future engineers with an integrated understanding of creativity.

PDE is fortunate to have this embedded in their program and this is something that other engineering disciplines should leverage off. In this respect, the study supports de Vere's (2009) argument that engineering should see design pedagogy as a model and potential for enhancing creativity. The most important thing is to make creativity a core part of the whole engineering curriculum, and not only be part of the design units.

7.4.1 Limitations of the Study

Finally, a number of limitations need to be considered. When comparing the cohort of students in PDE and ME, a study could be done to see if PDE units were attracting different types of students than ME was attracting, in terms of whether PDE was attracting more creative minded students. This study made no assumptions about the qualities of the students in the different units of ME and PDE. No comparison was made at the time of the study. Some differences might have occurred due to the different interests and characteristics of these two types of students. Therefore, the general application of these results is subject to certain limitations.

The study did not examine how the studied students approached problem-solving in other units or in their personal lives. The researcher did not have the chance to observe students' creative design processes when they were not in the observed lectures and tutorials. The author did not build peer communication with the students. Rather, the author established peer relationships with the instructors. Establishing similar relationships with the students might have brought different insights to the study.

The biggest limitation of this research was the 3-year PhD duration, which did not allow a longitudinal study. First, observation was conducted in ME design units to better understand the situation and identify the issues around creativity. Then action research was conducted in two design units for the following two semesters. After the action research process, a better planned experiment could have been conducted by identifying the previous issues and failures of the interventions. However, the studied ME units were only run once a year, which made it not possible to run a third experiment. Instead, the underlying reasons of the failures were tried to be identified by conducting additional in-depth interviews with the participants.

Another limitation was that the author was not in the position of decision. She was not the unit convener who is in charge of coordinating the units, nor was an instructor in class who was in communication with the students. Therefore, many of the interventions have not been fully applied as she suggested. Instead, she questioned the reasons why some of the actions worked and some did not and tried to describe them in Chapter 7.

7.4.2 Future Work

The findings in this study predominately focused on two engineering design units in ME in a specific university. Therefore, the results may not be applicable to theoretical units or to other engineering units in other universities. The results gained through this research may be conducted by other educational institutions having similar issues in similar contexts.

Because the findings of the study depend on two Action Research cases in one university with the same cohort of instructors and students it may not reflect the whole picture. Therefore, further research, following a similar approach, is suggested to be carried out in different universities in Australia and the rest of the world. Similar studies can be conducted in different disciplines too. However, it is suggested that future researchers focus on units that have a PBL element in them, as this would allow the experience of a creative process.

One possible area of future research would be to better understand the relationship between product performance and product creativity. In future investigations, it might be possible to conduct a comparative study with two different instructor approaches, a performance approach and a creativity approach, to see the effects on student creativity.

Another possible area would be to conduct a follow-up study in the same university and in the same units by considering all the results explained in this thesis.

At the time of finishing this thesis, early in 2017, a new unit titled "Engineering, Design and Innovation" was being introduced to all first-year engineering students enrolled at Swinburne University of Technology. This new unit was written and implemented by my two supervisors and is testament to the research outcomes of this thesis. It shows the impact that the work done has influenced change within the current engineering program with the intention of building creativity skills at an early stage of the students' engineering degree. It is to be taught to all engineering Majors and is delivered in partnership with Engineers Without Borders (EWB) and allows students to come up with solutions to various EWB challenges. The structure of the unit was largely based on my recommendations and involves more than one instructor in a tutorial, uses tutorials in a manner that allows students to have an open collaborative environment, expects students to do presentations each week and has design sessions every week where students learn basic sketching/visualisation skills to express themselves during the problem-solving process. These creative problem-solving techniques and fundamental design skills are all built into the assessment and result in 50% of the subject mark. Again, one of my recommendations giving equal assessment weighting to the design process as well as to the final outcome. This has allowed regular feedback from instructors and assisted the students significantly when working on open-ended problems set by EWB.

This is justification for what has been proposed in this thesis and I also had the chance to be a tutor in this unit and shared my experiences with the other tutors and the unit convener. Therefore, it would be interesting to study the effect of this newly designed unit in terms of how it enhances creativity to promote innovation within the engineering curriculum. Certainly, something I will pursue post-doctoral to keep promoting the importance of creativity to the engineering discipline.

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APPENDICES

Due to size limitation only relevant pages of the pdf files are included in the Appendix.

Appendix I

Engineering Design Methods (Cross, 2008)

1. During the “Identifying opportunities” phase the “user scenarios method” is used. The objective is to identify and define circumstances for improving or designing a new product. The Designer needs to understand the requirements of the users to learn from them. Next, they create relevant hypothetical user scenarios and define preliminary objective, constraints and criteria.

2. During the “Clarifying objectives” phase the goal is to analyse design objectives and their relations between each other. It starts with preparing objectives, then listing them in a hierarchical order, which is called “objectives tree”. Main and sub objectives are all visualised on this tree diagram, showing all the hierarchical interconnections.

3. During the “Establishing functions” phase, the “function analysis” method is used. This process begins with defining the essential functions, then by breaking down them into sub functions. A boundary is drawn defining the limits of the product to be designed. Lastly, for each sub function, an appropriate component is searched. This phase is focusing on what needs to be done rather than how.

4. During the “Setting requirements” phase, the process of solving design problems starts. One of the most important steps is to set certain limits and constraints, which can be related with time, cost, safety or physical aspects of the product. All these requirements establish the “performance specification”. It is important to set up an accurate and appropriate level of specifications early in design process.

5. During the “Determining characteristics” phase, the relationship between attributes and characteristics needs to be understood. Attributes represent the clients’ point of view, whereas characteristics represent the designers’ and engineers’ points of view.

The “Quality function deployment” method is described as matching customer requirements to engineering.

6. During the “Generating alternatives” phase the “morphological chart” method is used. It is during the design phase where creative thinking takes place for developing alternative solution ways. It is “the reordering and recombination of existing elements” (p. 137). The procedure starts with listing the essential features and functions of the product. For each feature or function, ways of solution ideas are written in a chart. Lastly, the appropriate feasible solution combination is identified for each function.

7. During the “Evaluating alternatives” phase, designers need to select the best design alternative. In this phase, the “weighted objectives” method is used. Design objectives are listed and ordered, and relative weightings are assigned to the objectives. Then parameters are established for each performance. With a final comparison and calculation, the best alternative with the highest score is selected.

8. During the last “Improving details” phase, the values of the functions and the costs of the components are examined. The goal is to increase the product value and to reduce the cost. All alternatives are evaluated and necessary improvements are decided. Cross-reduction can be done by eliminating functions, reducing components, simplifying the overall design of standardizing. This method is called “value engineering”.

Appendix II

Creativity assessment matrix developed by Treffinger et al. (2002)

4 Categories	Specific characteristics
Generating ideas	Fluency Flexibility Originality Elaboration Metaphorical thinking
Digging deeper into ideas	Analysing Synthesizing Reorganizing/redefining Evaluating Seeing relationships Desiring to solve ambiguity Bringing order/disorder Preferring complexity Understanding complexity
Openness and courage to explore ideas	Problem sensitivity aesthetic sensitivity Curiosity Sense of humour Playfulness Fantasy and imagination Risk-taking Tolerance for ambiguity Tenacity Openness to experience Emotional sensitivity Adaptability Intuition Willingness to grow Unwillingness to accept authoritarian assertions without critical examination Integration of dichotomies or opposites
Listening to one's inner voice	Awareness of creativeness Persistence or perseverance Self-direction Internal locus of control Introspective Freedom from stereotyping, Concentration Energy Work ethic

- ***"Generating ideas"***

"Fluency" is "the ability to generate a large number of ideas in response to an open-ended question". "Flexibility" is "the ability to shift the direction of one's thinking or to change one's point of view". "Originality" is "the ability to generate new and unusual ideas". "Elaboration" is "the ability to add details and to make ideas richer, more interesting, or more complete". "Metaphorical Thinking" is "the ability to use comparison or analogy to make new connections" (Treffinger et al., 2002).

- ***"Digging deeper into ideas"***

"Analysing and synthesizing" refer to "sorting and evaluating promising ideas under the microscope for closer examination, deciding, choosing". "Reorganizing or redefining" are “setting priorities, sorting, arranging, and categorizing ideas”. “Evaluating” is examining ideas. “Seeing relationships” is exploring the relations between concepts. “Desiring to resolve ambiguity” is “bringing order to disorder”. “Complexity” is “understanding complexity” (Treffinger et al., 2002).

- ***“Openness and courage to explore ideas”***

“Aesthetic sensitivity” is being sensitive or interested in aesthetics. “Playfulness” is having sense of humour and being childish. “Fantasy and imagination” is capacity for fantasy or imagination. “Risk-taking” is thrill seeking. “Emotional sensitivity” is being open to feelings and emotions. “Adaptability” is being able to adapt in different circumstances. “Willingness to grow refers to learning from their mistakes (Treffinger et al., 2002).

- ***“Listening to one’s inner voice”***

“Awareness of creativeness” refers to “seeing himself/herself as creative being self-confident”. “Self-direction” is “the need for and/or demonstration of autonomy, self-discipline”. “Internal locus of control” is independence of thought, being courageous, not fear being different. “Reflective thinking” is introspection. “Freedom from stereotyping” is rejecting and being free from stereotypes. “Concentration” is intense concentration and absorption in work. “Energy” is being energetic, hyperactive. “Work ethic” is “willing to work hard, liking and capacity for thinking and work” (Treffinger et al., 2002).

4 creativity characteristics to assess and 4 levels of assessment:

	Not yet evident	Emerging	Expressing	Excelling
Generating ideas				
Digging deeper into ideas				
Openness and courage to explore ideas				
Listening to one’s inner voice				

“Not yet evident”: The “person's present level of performance does not reveal characteristics” or behaviours “that are consistent with the selected definition of creativity”.

“Emerging”: The evidence of creativity is limited; it is beginning to emerge.

“Expressing”: Signs of creativity characteristics can be observed in a regular basis in student’s behaviour or products and the signs are high quality.

“Excelling”: There are excelling creativity characteristics are present with high level of depth quality and originality.

Appendix III

Creative Solution Diagnosis Scale

The mark for creativity will be based on the following formula:
R&E (2.5 x Nov/100 + 1.5 x Eleg/100 + 1 x Gen/100)

R&E is either 1 or 0 and is based on the satisfaction of the indicators under R&E
Nov is out of 100* for the Novelty section
Eleg is out of 100* for the Elegance section
Gen is out of 100* for the Genesis section
*100 if at least half the respective indicators are satisfied, 50 for at least one and the rest scaled in between

Creativity indicators
Relevance & Effectiveness CORRECTNESS (the solution accurately reflects conventional knowledge and techniques) PERFORMANCE (the solution does what it is supposed to do) APPROPRIATENESS (the solution fits within task constraints) OPERABILITY (the solution is easy to use) SAFETY (the solution is safe to use) DURABILITY (the solution is reasonably strong)
Novelty DIAGNOSIS (the solution draws attention to shortcomings in other existing solutions) PRESCRIPTION (the solution shows how existing solutions could be improved) PROGNOSIS (the solution helps the beholder to anticipate likely effects of changes) REPLICATION (the solution uses existing knowledge to generate novelty) COMBINATION (the solution makes use of new mixture[s] of existing elements) INCREMENTATION (the solution extends the known in an existing direction) REDIRECTION (the solution shows how to extend the known in a new direction) RECONSTRUCTION (the solution shows an approach previously abandoned is still useful) REINITIATION (the solution indicates a radically new approach) REDEFINITION (the solution helps the beholder see new, different ways of using the solution) GENERATION (the solution offers a fundamentally new perspective on possible solutions)
Elegance RECOGNITION (the beholder sees at once that the solution “makes sense”) CONVINCINGNESS (the beholder sees the solution as skillfully executed, well-finished) PLEASINGNESS (the beholder finds the solution neat, well done) COMPLETENESS (the solution is well worked out and “rounded”) GRACEFULNESS (the solution is well proportioned, nicely formed) HARMONIOUSNESS (the elements of the solution fit together in a consistent way) SUSTAINABILITY (the solution is environmentally friendly)
Genesis FOUNDATIONALITY (the solution suggests a novel basis for further work) TRANSFERABILITY (the solution offers ideas for solving apparently unrelated problems) GERMINALITY (the solution suggests new ways of looking at existing problems) SEMINALITY (the solution draws attention to previously unnoticed problems) VISION (the solution suggests new norms for judging other solutions— existing or new) PATHFINDING (the solution opens up a new conceptualization of the issues)

Appendix IV

The learning style models used in engineering education (Felder, 1996):

The Myers-Briggs Type Indicator (MBTI)

This type “classifies students according to their preferences on scales derived from Carl Jung’s theory of psychological types” (Felder, 1996, p. 18). Students may be “extroverts or introverts, sensors or intuitors, thinkers or feelers, judgers or perceivers”. Engineering educators take mostly into consideration the introverts by presenting lectures “rather than emphasizing active class involvement and cooperative learning”. They focus “on engineering science rather than design and operations” (Felder, 1996, p. 18).

Kolb’s Learning Style Model

There are four types of learners: Type 1 asks “Why?”, Type 2 asks “What?”, Type 3 asks “How?” and Type 4 asks “What if?” questions to themselves. Felder (1996) argues that traditional engineering education focuses only on formal presentation of lecturing, asking only “what” question, but not the others. The closest learning style to design is “What if”. However, the best way to learn a concept is being able to answer all the questions (Terry & Harb, 1993).

Herrmann Brain Dominance Instrument (HBDI)

“This method classifies students in terms of their relative preferences for thinking in four different modes based on the task-specialized functioning of the physical brain” (Felder, 1996, p. 20). Felder (1996) argues that engineering educators are logical, analytical, structured, factual and critical. They focus on these aspects. However, they neglect the creative problem-solving systems thinking by not considering visual, innovative, emotional, sensory and holistic learners.

Felder-Silverman Learning Style Model

This model classifies students as “sensing or intuitive, visual or verbal, inductive or deductive, active or reflective, sequential or global learners”. Felder (1996) argues that engineering education neglects “intuitive, verbal, deductive, reflective, and sequential learners” (p. 19).

Appendix V

Interview questions for tutors/lecturers

- What do you understand from creativity in the context of engineering?
- What is the main purpose of this subject? (Designing, writing report, framing, and etc.)
- What is the major outcome of the design project? (Design process, product, and etc.)
- Is creativity an assessment criterion? Why/why not? Is it indicated in the class? Is it a bonus, or is it necessary? Do you think the students are aware of it? Do you give any reward (grade, motivation) for creativity? How?
- What have you done to help students to develop their creative thinking and abilities?
- What challenges do you meet in fostering creativity in class? How do you deal with these challenges?
- Do you think teamwork encourages creativity? In what ways? What about individual work or groups with different number of students in teams?
- In the assessment, if the percentage of design is increased what advantages or disadvantages can it bring about creativity?
- How do you think using a textbook (Engineering Design Methods, Cross, 2008) affects creativity? Have you ever taught this subject not depending on a book?
- Why there is a competition in the end? What advantages does it bring? Do you think competition increases or reduces creativity? How?
- Do you change any physical conditions of the classroom to prepare the atmosphere for a more suitable environment for creativity?
- Do you have any suggestions how to enhance creativity within this subject?
- Apart from this subject, how do you think creativity can be promoted more or taught inherently in engineering faculties? Any suggestions?
- When you were studying at the university did you have any unit without an exam?
- Can you compare the engineering education that you got and the current education?
- How did you generate ideas when you were studying? Have you ever applied any creativity tools for idea generation process in your design units when studying? Were you expected to keep a folio / a design journal?
- When you were expected to come up with solutions to given problems where was the emphasis; on creativity, or on performance?
- Have you done any presentations in class during design process?

Appendix VI

Checkland's Soft System Methodology (SSM) by Williams (2005):

Step 1 and 2 – The Situation Defined

Because human affairs are complex to understand, the first step is "to acknowledge, explore and define the situation" (Checkland, 2000). It is the phase of deciding what is actually being explored. There is no need to define the problem yet, but it is essential to assess the general issue that interests the researcher. At this stage, it is suggested to collect as much data as possible (Williams, 2005).

The second step is the expression phase in which the issue is expressed in a comprehensive way. Williams (2005, p. 3) summarised Checkland's guidelines, explaining what to include at this stage: "Structures, processes, climate, people, issues expressed by people, conflicts". Checkland (2000) suggests the best way of doing this is to use a picture form. To show "the complexity of human interacting relationships; pictures can be taken in as a whole and help to encourage holistic rather than reductionist thinking about a situation" (Checkland, 2000, p. 22). This is the unstructured expression. Chapter Four explains where the situation is defined thoroughly and the issues are expressed by using pictures and hand drawn graphs.

Step 3 – Root definitions of relevant systems

It is the "unique and most challenging part of the methodology" (Williams, 2005, p. 5), named as "root definition" (Checkland, 2000). "The first step is to understand the concept of different perspectives that are possible to draw out of the rich picture" (Williams, 2005, p. 5). To build a model of a complex concept one first has to make a clear definition of the purpose of the activity to be modelled (Checkland, 2000). Then it is time to apply the chosen perspective to a structured model development, as addressing all the perspectives as a whole is too complex. So, the issues need to be clarified separately (Williams, 2005).

Step 4 – Developing the model

This is the model development stage. There are many ways of doing this, however, literature (Checkland, 2000; Williams, 2005) suggests writing down the activities as a list, selecting the items that could be done at once, placing these activities in line, and then organizing those that are dependent on the first activities and finally rearranging the list to avoid overlapping arrows. Checkland (2000) warns not to spend too much time developing the initial model. He recommends doing comparisons, having discussions, gaining insights and then returning back to the model again. “The SSM process is about cycles of discussion, debate and learning rather than producing the ideal solution first time” (Williams, 2005, p. 11). Checkland (2000) suggests answering three questions while developing the model: “What to do?, How to do it?, Why do it?”. All the interventions during the action research explained in Chapter Five, are planned considering these three questions.

Step 5 and 6 – Exploring the situation

Step 5 is for structuring the further questioning of the situation (Checkland, 2000). The model needs to be compared with reality to develop insights. Checkland (2000) warns not to confuse reality with the model and suggests modelling the real world by using the same structure as the conceptual one.

Step 6 is to “develop desirable and feasible interventions”. At this stage, the methodology needs to start “swinging back and forth through all seven stages of the methodology” in order to gain full potential (Williams, 2005, p. 17).

Step 7- Action to improve the situation

At this stage, an action is taken to improve the situation. “This is where the methodology comes full cycle, and may be starts a new cycle” (Williams, 2005, p. 18). In Chapter Five, the affects and results of the first action research in MD interventions are discussed to develop more feasible interventions for the next action research in MSD.

Appendix VII

Approval for SHR Project 2014/200

From: Kaye Goldenberg
To: Clint Steele; Yasemin Tekmen Araci
Subject: SHR Project 2014/200 Ethics Clearance
Date: Thursday, 11 September 2014 11:09:21 AM
To: Dr Clint Steele, FSET/ Ms Yasemin Tekmen Araci

Dear Dr Steele
SHR Project 2014/200 Exploring ways of integrating creativity in undergraduate engineering curriculum to foster creative skills among engineering students during problem solving process in engineering design subject
Dr Clint Steele, FSET/ Ms Yasemin Tekmen Araci
Approved Duration: 11/09/2014 to 30/04/2018 [Adjusted]
I refer to the ethical review of the above project protocol by a Subcommittee (SHESC1) of Swinburne's Human Research Ethics Committee (SUHREC) at a meeting held 15 August 2014. Your response to the review, as emailed on 20 August, with attachments, was put to a Subcommittee delegate for consideration.
I am pleased to advise that, as submitted to date, the project may proceed in line with standard ongoing ethics clearance conditions here outlined.
- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the current National Statement on Ethical Conduct in Human Research and with respect to secure data use, retention and disposal.
- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.
- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.
- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project. Information on project monitoring, self-audits and progress reports can be found at: http://www.research.swinburne.edu.au/ethics/human/monitoringReportingChanges/
- A duly authorised external or internal audit of the project may be undertaken at any time. Please contact the Research Ethics Office if you have any queries about on-going ethics clearance. The SHR project number should be quoted in communication. Researchers should retain a copy of this email as part of project recordkeeping.

Best wishes for the project.
Yours sincerely,
Kaye Goldenberg
Acting Secretary, SHESC1

Appendix VIII

Approval for SHR Project 2014/255

From: Kaye Goldenberg
To: Clint Steele; Yasemin Tekmen Araci
Subject: SHR Project 2014/255 Ethics Clearance
Date: Thursday, 6 November 2014 4:22:17 PM
To: Dr Clint Steele, FSET/ Ms Yasemin Tekmen Araci

Dear Dr Steele,
SHR Project 2014/255 Exploring ways of integrating creativity in undergraduate engineering curriculum to foster creative skills among engineering students during problem solving processes in engineering design subject
Dr Clint Steele, FSET/ Ms Yasemin Tekmen Araci
Approved Duration: 06/11/2014 to 30/04/2018 [Adjusted]
I refer to the ethical review of the above project protocol by a Subcommittee (SHESC3) of Swinburne's Human Research Ethics Committee (SUHREC) at a meeting held 10 October 2014. Your responses to the review, as emailed on 24 October and 4 November were reviewed by a SHESC3 delegate.
I am pleased to advise that, as submitted to date, the project may proceed in line with standard ongoing ethics clearance conditions here outlined.
- All human research activity undertaken under Swinburne auspices must conform to Swinburne and external regulatory standards, including the current National Statement on Ethical Conduct in Human Research and with respect to secure data use, retention and disposal.
- The named Swinburne Chief Investigator/Supervisor remains responsible for any personnel appointed to or associated with the project being made aware of ethics clearance conditions, including research and consent procedures or instruments approved. Any change in chief investigator/supervisor requires timely notification and SUHREC endorsement.
- The above project has been approved as submitted for ethical review by or on behalf of SUHREC. Amendments to approved procedures or instruments ordinarily require prior ethical appraisal/clearance. SUHREC must be notified immediately or as soon as possible thereafter of (a) any serious or unexpected adverse effects on participants any redress measures; (b) proposed changes in protocols; and (c) unforeseen events which might affect continued ethical acceptability of the project.
- At a minimum, an annual report on the progress of the project is required as well as at the conclusion (or abandonment) of the project. Information on project monitoring, self-audits and progress reports can be found at:
http://www.research.swinburne.edu.au/ethics/human/monitoringReportingChanges/
- A duly authorised external or internal audit of the project may be undertaken at any time. Please contact the Research Ethics Office if you have any queries about on-going ethics clearance. The SHR project number should be quoted in communication. Researchers should retain a copy of this email as part of project recordkeeping.
Best wishes for the project.

Yours sincerely,
Kaye Goldenberg
Acting Secretary, SHESC3

Appendix IX

Consent information statement for observation

Title
Exploring ways of integrating creativity in undergraduate engineering curriculum to foster creative skills among engineering students during problem solving process in engineering design subject

Investigators:
Yasemin Tekmen Araci – Student Investigator
Dr Clint Steele – Chief Investigator, FSET
Dr Blair Kuys - FHAD
Dr Llewellyn Mann - FSET

The aim of this research is to examine and explore ways of fostering creativity and nurturing creative thinking skills, finding ways of developing a framework for implementing the findings into curriculum. The answer will try to be given is how we can embed creativity in engineering curriculum. Before taking any action, in order to get a deeper understanding, observation is needed to actually see what is in engineering curricula at the moment about creativity, what are the creativity instances in engineering subjects, how is the structure of engineering subjects influencing student behaviour, what might be the creativity blockers and how creativity and innovation approached in the classroom.

Observation will be undertaken in MEE40002 Mechanical Engineering Design lectures and tutorials. The student investigator will take notes in a Mechanical Engineering Design lecture and in 2 tutorials each week over the 12 weeks of semester. The collected data will be qualitative notes, and will give a direction how to go further in the research.

The student investigator will be the only researcher undertaking the observation, and will not interact with the students or the tutors. No names or identifiers will be recorded. She is not involved in the marking of the students. The de-identified observation notes will be used to inform the student investigator's PhD thesis. Conference papers and a journal article may also result from this study. The data will not be used for any other purpose. Observation notes will be stored in a locked filing cabinet in the Student Investigators office. All collected data will be kept by the supervisor Dr Clint Steele for 5 years after completing the research and the student investigator submitting her PhD, then destroyed.

If you would like further information about the project, please do not hesitate to contact:
Dr Clint Steele, Swinburne University Hawthorn Campus EN 709
+61 9214 8449 / csteele@swin.edu.au

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human Research*. If you have any concerns or complaints about the conduct of this project, you can contact: Research Ethics Officer, Swinburne Research (H68), Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122. Tel (03) 9214 5218 or +61 3 9214 5218 or resethics@swin.edu.au

If you do not wish for the Student Investigator to observe this class please let either her or your tutor know.

Appendix X

Consent Information Statement for Survey – Tutors

Project Title

Exploring ways of integrating creativity in undergraduate engineering curriculum to foster creative skills among engineering students during problem solving processes in engineering design subjects.
Investigators

Yasemin Tekmen Araci – Student Investigator, PhD Student, FSET
Dr Clint Steele – Chief Investigator, FSET
Dr Blair Kuys - FHAD
Dr Llewellyn Mann - FSET

Project Overview

The aim of this research is to examine and explore ways of fostering creativity, nurturing creative thinking skills and developing a framework for implementing the findings into mechanical engineering curricula. The survey is about understanding the creativity culture in Product Design Engineering studio subjects, how it occurs and how it is affected by internal or external factors.

Your Participation & Participant Rights and interests

As part of my PhD I am inviting you to take this survey. There is minimal risk to you participating in this survey. Only the project team will have access to the results. There will be no personal questions involved. All data will be stored in a locked filing cabinet in the Student Investigators office. After completing the study, they will be kept by the supervisor Dr Clint Steele for 5 years then destroyed.

Participation is voluntary and you can withdraw at any stage. Your participation will have no influence on your relationship with Swinburne. In any case, if you feel upset there is Swinburne Student Development and Counselling freely available for your needs.

It is possible that sensitive information may be collected from you. Since the lecturer of the subject is involved in this project as the Chief Investigator, data of sensitive nature will be collected and analysed by Student Investigator and only aggregate results will be made available to Chief Investigator.

There are no right answers to the questions, so please feel free to answer how you think is right for you. I am not here to judge nor evaluate your performance. I am just investigating the happenings of creative thinking.

Research output

The survey results will be used to inform the student investigator's PhD thesis. Conference papers and journal articles may also result from this study. The data will not be used for any other purpose. No individual will be identified in any publication.

If you would like further information about the project, please do not hesitate to contact:

Yasemin Tekmen Araci
ytekmenaraci@swin.edu.au

Dr Clint Steele
Swinburne University Hawthorn Campus EN 709
+61 9214 8449
csteele@swin.edu.au

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human Research*. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.
Tel (03) 9214 5218 or +61 3 9214 5218 or resethics@swin.edu.au

Appendix XI

Consent Information Statement for Interview – Students

Project Title

Exploring ways of integrating creativity in undergraduate engineering curriculum to foster creative skills among engineering students during problem solving processes in engineering design subjects.

Investigators

Yasemin Tekmen Araci – Student Investigator, PhD Student, FSET
Dr Clint Steele – Chief Investigator, FSET
Dr Blair Kuys - FHAD
Dr Llewellyn Mann – FSET

Project Overview

The aim of this research is to examine and explore ways of fostering creativity, nurturing creative thinking skills and developing a framework for implementing the findings into mechanical engineering curricula. The interview is about understanding the creativity culture in Product Design Engineering studio subjects, how it occurs and how it is affected by internal or external factors.

Your Participation & Participant Rights and interests

As part of my PhD I am inviting you to participate in an interview, which will take about 30 minutes. There is minimal risk to you participating in this interview. Participation is voluntary and you can withdraw at any stage. Your participation will have no influence on your grades or your future relationship with Swinburne. The lecturer of the subject is involved in this project as the Chief Investigator, but there is no obligation of participating and all data will remain confidential and anonymous. In any case, if you feel upset or depressed there is Swinburne Student Development and Counselling freely available for your needs.

The interview will be recorded with an electronic device and then all data will be transferred to a DVD. All data, along with the consent forms, will be stored in a locked filing cabinet in the Student Investigators office. After completing the study they will be kept by the supervisor Dr Clint Steele for 5 years then destroyed.

It is possible that sensitive information may be collected from you. Since the lecturer of the subject is involved in this project as the Chief Investigator, data of sensitive nature will be collected and analysed by the Student Investigator and only aggregate results will be made available to Chief Investigator. The identities of the participants will always stay confidential and no individual names will be used in any of the research outputs.

There are no right answers to the questions, so please feel free to answer how you think is right for you. I am not here to judge nor evaluate your performance. I am just investigating the happenings of creative thinking.

Research output

The interview results will be used to inform the student investigator's PhD thesis. Conference papers and journal articles may also result from this study. The data will not be used for any other purpose. No individual will be identified in any publication.

If you would like further information about the project, please do not hesitate to contact:

Yasemin Tekmen Araci
ytekmenaraci@swin.edu.au

Dr Clint Steele
Swinburne University Hawthorn Campus EN 709
+61 9214 8449
csteele@swin.edu.au

This project has been approved by or on behalf of Swinburne's Human Research Ethics Committee (SUHREC) in line with the *National Statement on Ethical Conduct in Human Research*. If you have any concerns or complaints about the conduct of this project, you can contact:

Research Ethics Officer, Swinburne Research (H68),
Swinburne University of Technology, P O Box 218, HAWTHORN VIC 3122.
Tel (03) 9214 5218 or +61 3 9214 5218 or resethics@swin.edu.au

Date : ……………………………

Name : ……………………………

Signature : …………………………….

Appendix XII

A semi-structured non-participant observation protocol

Date		Place	
Time		Lecture/Tutorial	
Week			

Classroom	Seats
Environment	Size
	Light
	Sound
	Extra
	Creativitybloker

How many students		Seating plan	
Arrival/departure time			

General mode of students	Coming/going on time
	Taking notes
	Doing assignments in time
	Patterns of student behaviour (following class/ talking to each other/playing with mobile/eating drinking)
	Structure of teams / team dynamics

Students communication with each other	type of language they use (verbally/body language)
	thinking/talking/listening/writing/drawing/arguing/discussing
	type of questions they ask/how they solve problems/their aaproach
	type of thinking/creativity tools used mentioned in class/written in the book/smth extra conscious or uncoscious

Students communication with lecturer/tutor	type of questions asked
	what is expected from tutor
	general communication with tutor
Students	Challenges in problem solving process (do they struggle, in which part)
Lecturer/Tutor	general attitude/mode (friendly/strict/open/motivational/criticising...)

way of conducting the session (presentation/talking/describing/showing/discussion...)
time management
type of questions asked to students
clarification what is expected from students (general/each week)
feedbacks
suggesting/promoting creativity. How?

For further investigation (interview/questionnaire)

Questions might be asked to students	
Questions might be asked to tutors/lecturer	

Appendix XIII

Questions tried to be answered during the observations

Students

What kind of thinking tools students are using in class when problem solving?

Do the students use any creative tools / methods, or any kind of media, which helps fostering creativity?

How does the product development / design process evolve?

In problem solving process are students more problem focused or solution focused?

Can we easily see the phases of creative design process, and what are the significant issues for these phases?

"How do various factors, including the course structure and the instructor influence student choices to pursue creative opportunities?" (Dym, Little, & Orwin, 2014).

Instructors

How is the instructor approached during the class hours?

How does the interaction progress between the students and the instructors?

How do the instructors communicate with the students?

Do the instructors suggest / encourage any creative tools to be used during the problem-solving process?

Do the instructors give promotion for creative works? Is there a motivation for it?

Environment

How is the learning environment structured?

What kind of atmosphere is prepared for students?

What types of problems are given? How are the problems structured?

What is the general feeling in the class?

What are the physical situations in the classroom? (Sitting plan, size of the classroom, desks…)

Are there any issues that might cause blocking the creativity?

Appendix XIV

Survey for students in Mechanical Systems Design

Exploring ways of integrating creativity in undergraduate engineering curriculum to foster creative skills among engineering students during problem solving processes in engineering design subject

Student Investigator: Yasemin Tekmen Araci (ytekmenaraci@swin.edu.au)
Chief Investigator: Clint Steele (csteele@swin.edu.au)

SWINBURNE UNIVERSITY OF TECHNOLOGY

Your Course (Please tick)

Product Design Engineering ☐ Mechanical Engineering ☐ Other:…………….

What is your learning style?

Please circle.

Visual Auditory Kinaesthetic (By doing) Don't know

1. What does creativity mean to you?
2. Do you think an engineer needs creativity? Why?
3. Please circle three words/properties that you think represents the characteristics of creativity / creative output in an engineering context

INNOVATIVE	ORIGINAL	USEFUL	NEW
COMPLEX	UNIQUE	NONOBVIOUS	NOVEL
FLEXIBLE	LOGICAL	FUNCTIONAL	INGENUOUS
EFFECTIVE	APPROPRIATE	SURPRISING	IMAGINATIVE
AESTHETIC	ARTISTIC	EXCITING	AMBIGIOUS
DIFFERENT	UNEXPECTED	UNDERSTANDABLE	

OTHER ……………………………………………………………………………………

4. Do you think creativity is important in your engineering education?

5. How creative do you think you are? Please circle. (1: not at all, 7: highly creative)

1 2 3 4 5 6 7

not at all highly creative

6. How creative do you think that you were during this unit? Please circle.

(1: not at all, 7: highly creative)

not at all	1	2	3	4	5	6	7	highly creative

7. What was the most effective lecture / week / assignment for your creative skill development? Why?

8. Do you think that creativity is promoted/taught in your unit? How could it be better developed?

9. Do you think in your team everybody has used their full potential of creative abilities?

10. Is creativity an assessment criterion for your design in this subject?

YES NO Not Sure

11. Would you prefer to work alone or within a group, for design projects? Why?

12. Can you describe a classroom setting in which you think you will be more creative? (Location, sound, light, conformity, appropriateness, seating plan, size, furniture and etc.)

13. Which do you prefer: CAD drawing or freehand drawing to communicate with your team members / with your tutor? With which are you most comfortable?

14. How much do you think freehand drawing skill is important for engineering? Please circle one number. Please circle (1: Not important at all, 7: Very important)

Not important at all	1	2	3	4	5	6	7	Very important

15. Do you think there are elements missing from this unit that would improve your creative thinking skills?

16. Please answer if you are studying Product Design Engineering:

Please provide a brief description of the differences between the design subjects conducted in Mechanical Engineering and Product Design Engineering?

THANK YOU FOR YOUR TIME

Appendix XV

Survey for lecturer/tutors (PDE)

Exploring ways of integrating creativity in undergraduate engineering curriculum to foster creative skills among engineering students during problem solving processes in engineering design subject

Student Investigator: Yasemin Tekmen Araci (ytekmenaraci@swin.edu.au)
Chief Investigator: Clint Steele (csteele@swin.edu.au)

How long have you been teaching this unit? ………… years

1. What does creativity mean to you?

2. Do you think an engineer needs creativity? Why?

3. Please circle three words/properties that you think represents the characteristics of creativity / creative output in an engineering context

INNOVATIVE	ORIGINAL	USEFUL	NEW
COMPLEX	UNIQUE	NONOBVIOUS	NOVEL
FLEXIBLE	LOGICAL	FUNCTIONAL	INGENUOUS
EFFECTIVE	APPROPRIATE	SURPRISING	IMAGINATIVE
AESTHETIC	ARTISTIC	EXCITING	AMBIGIOUS
DIFFERENT	UNEXPECTED	UNDERSTANDABLE	

OTHER ………………………………………………………………………………

4. What are the students expected to gain from this subject in terms of creativity?

5. In general how would you rate your students creativity in this subject?

1 2 3 4 5 6 7

not at all highly creative

6. How would you rate the subject in helping students develop creative skills?

1 2 3 4 5 6 7

not successful at all very successful

7. What are the key components in a successful creative process?

8. Can you describe a situation of a student in a creative process?

THANK YOU FOR YOUR TIME

Appendix XVI

Interview questions for students

- What did you find difficult/challenging about this unit? Did you overcome these difficulties, how?
- Can you please describe with your own words your creative process of idea generation for the design project?
- Do you prefer to generate ideas by writing, talking, drawing, visualising, building etc.?
- Can you tell about a specific experience of yours where your creative skills improved? What helped you most?
- What challenges did you meet in fostering creativity? How do you deal with these challenges?
- What do think about the team dynamics of your group in this subject? What do you think is the relationship between the team dynamics and creativity?
- Do you think competition increases or decreases creativity? How?
- Do you think your lecturer/tutors encourage creative thinking?
- What can be done to foster students' creativity more? Any suggestions?

PART B Your unit in more detail

Ongoing Unit Improvements

Based on student and staff feedback collected when this unit was last offered, the Unit Panel has implemented the following improvements and updates:

- A major issue from last year was students' ability to digest abstract design cognition information within the lectures. To correct this, the lectures will be pre-recorded to give students a chance to digest information as needed.

Teaching Staff

Name	Role	Campus & Room No.	Phone No.	Email Address	Consultation Times
This part is covered due to the confidential information.					

Learning and Teaching Structure

Teaching Activity	Total Hours	Hours per Week	Semester Weeks
Lectures	24 hours	2 hours	Weeks 1 to 12
Tutorials	24 hours	2 hours	Weeks 1 to 12

In a Semester, you should normally expect to spend, on average, twelve and a half hours of total time (formal contact time plus independent study time) a week on a 12.5 credit point unit of study.

Week by Week Schedule

Week	Lecture	Tutorials	Deliverable
1	Understanding design • Nature • Ability • Process	Form project groups	Read chapters 1, 2 &3 of Cross before the lecture Read Cross and Clayburn Cross from the printed notes before the lecture Take the Zimbardo Time Perspective Inventory below: http://www.thetimeparadox.com/zimbardo-time-perspective-inventory/ Take the VAK learning style survey http://www.businessballs.com/freepdfmaterials/vak_learning_styles_questionnaire.pdf
2	Doing design: Part 1 (Getting ready) • Procedures	Reflect upon the design attitude of team members and the nature of the team's	Read chapters 4, 5, 6 & 7 of Cross before the lecture **Register** project groups with tutor

	• Objectives • Functions • Requirements	project. Choose a design process	
3	Doing design: Part 2 (Generating good designs) • Characteristics • Generating alternatives • Evaluating alternatives	Project – show your plan and literature to the tutor	Read chapters 8, 9, 10 & 11 of Cross before the lecture
4	Doing design: Part 3 (Auxiliary tools) • Value engineering • Robust methods • Concurrent engineering	Project – show alternatives to tutor	Read chapter 12 of Cross before the lecture Read Robust Design from the printed notes Read Concurrent Engineering from the printed notes before the lecture
5	Managing design • Strategies • Product development Design for X	Project – explain to tutor which design has been chosen and what you will do to finalise it.	Read chapters 13 & 14 of Cross before the lecture Download Design for X from the printed notes before the lecture **Submit** Test 1 Part-A
6	Risk Engineering System Reliability	Design strategy exercise (1 of the 3 on page 201 of Cross) Design for X exercises – apply two Xs to your boat	Read section 1.4 of Safe Design before the lecture **Submit** Test 1 Part-B
7	Pressure vessels Thermal systems	Risk and reliability exercise	Download AS 1210 before lecture Read Thermal Systems in the printed notes before the lecture **Submit** Design project Part 2. Swap designs with others for review
8	Motive power systems Power transmission and storage systems	Pressure vessel exercise – Lowest 't' for given volume and length Thermal system exercise – Solar balloon	Read 'Motors, Mechanical Power Transmission and Energy Storage' and 'Fluid Power' from the printed notes before the lecture. Email review documents to the respective team representative, tutor and lecturer.

9	Human factors	Motive power, power transmission and storage exercise	Read Human Factors from the printed notes before the lecture.
10	Design cognition Critical thinking	Human Factors exercises	Read 'Design Cognition' and 'Logic and critical thinking' before the lecture
11	Environmental noise issues	Critical thinking exercises (random activities from the text) Review boat design decisions, then analyse personal design characteristics.	Read Industrial Noise Control from the printed notes before the lecture
12	Vehicle design	Various questions on industrial noise control	**Email** Assignment by Friday

Assessment

a) Assessment Task Details:

Tasks	Individual or Group task	Weighting	Assesses attainment of these ULOs	Assessment Due
Examination Component: 3 hour Final Exam	Individual	40%	1, 2, 4	Formal Exam Period
Test Component:	Individual	10%	1	Week 5 & 6
Assignment Component:	Individual	20%	3	Week 12
Project Report Component:	Group	15%	1, 2, 4, 5	Week 7
Design Component:	Group	15%	1, 2, 4, 5	19 Oct 2013

NOTE:

- For the examination the only calculator you are allowed to bring is the **Texas Instrument 30XB MultiView**. No spare calculators or batteries will be available.
- Specific assessment criteria for each assessment task can be found below in section C
- Students must retain all assessed material that contributes to the final result up until such time as the final results are published.

b) Minimum Requirements to pass this Unit of Study:

To pass a Faculty of Engineering and Industrial Sciences (FEIS) units, you must achieve:

i. at least 35% of the possible final marks for each Major Assessment Component plus
ii. an aggregate mark for the subject of 50% or more.
iii. any other minimum requirements to pass the unit, including participation requirements

If you do not achieve at least 35% of the possible final marks for each Major Assessment Component you will receive a maximum of 44% as your mark for the subject concerned.

c) Submission Requirements:

Design project 30%*

Type: Group work** (3-4 members). For options 1 and 4 one member (and one only) must be a non-mechanical engineering student (single or double degree) and at least 2 need to be mechanical. Additionally, each group must have at least one member that has a significant international element. It could be an international student or a student who spent considerable time in another country. The non-mechanical student can also be the student with an international element. Finally, each group needs at least 2 local students. These requirements are to expand your exposure to different design attitudes as much as possible.

Descriptions

Option 1

Students are to take on a project to develop a solar powered boat using the solar panels that can be borrowed from the library. Each boat will compete against the other boats in a race to one end of the pool and back (details of the pool will be discussed later) held as part of the Solar Vehicle challenge at Science Works on the weekend of 18th of October. The competition will be based on a round robin and each game will follow the format below:

1. All the teams will be broken up into 4 groups for a separate round robin each.
2. When called (by the team name that the team will provide their tutor after forming a group), competing boats will be placed at one end of the pool that is used by the Model Solar Challenge and fitted to the standard guidance system (a description of the pool can be seen in section 9 of this pdf - http://www.modelsolar.org.au/regulations/2013_boatRegulations_vic.pdf).
3. At the instruction of the adjudicator the boats will be let go to travel under their own power.
4. The boat that travels to the opposite end and returns to the starting position first is the winner.

The winner will receive 9 points a tie 4 points and a loser 1 point. Failure to appear when called will be viewed as a loss, and the other team will win. Unless that other team doesn't show, in which case both will be deemed to have lost. Finally, if neither boat appears to be operating, then this will be two losses also.

Design project Part 1: Performance – 15%*

The score for each team is the accumulated points from the round robin. Marks will then be allocated to each team based on the formula below.

$$M = 7.5\frac{S - S_L}{S_H - S_L} + 7.5$$

Where:
M is the mark in percentage
S is the score of the team being considered
S_L is the lowest score had by any team in the competition
S_H is the highest score had by any team in the competition

Note: if a team does not appear on the day, then they will receive a mark of zero.

The top 8 teams who choose to return will compete in a sudden death tournament. The winner of this tournament will then be given a certificate by from the Model Solar Vehicle Challenge organisation indicating that they were the best performing team for that year. Teams may modify their boats during the night for improved performance.

Option 2

If you have an interest in being a part of the Aurora team (which is now located at Swinburne), then you can opt to do a project on the car that they are developing instead. If this is of interest, then please contact the lecturer to get more information. You will need to design a sub-system for the car. More details can be seen here - http://new.aurorasolarcar.com/. Note, the basic layout of the car has been designed, and it is the sub-systems that need to be designed now. Because this is part of a greater project, you will need to attend the larger team meetings. The first of these will be on Thursday 7th of August. At this meeting you will be introduced to the senior members, put into groups and given a subsystem to work. There will also be a team BBQ afterwards.

Design project Part 1: Performance – 15%*

The final design will be presented to the core members of the Aurora team who will evaluate it, and give it a mark out of 15. This will then contribute to the final mark.

Option 3

Students will design a sub system of the SAE car for next year. This option is ideal for students who want to get a head start on SAE as their final year project. The team will select an appropriate (it must be agreed to by the tutor to ensure it is of sufficient complexity) sub system and then generate all required 3D CAD. For teams who have already started to design something for this year, you can also look at a proposed future design that is an improvement on what has been done this year.

Design project Part 1: Performance – 15%*

The final design will be presented to this year's SAE team who will evaluate it, and give it a mark out of 15. This will then contribute to the final mark.

Option 4

A newly developed electric scooter needs refinement to bring it to a level to show to potential business customers. This will require cooperation with students who designed the original system.

Design project Part 1: Performance – 15%*

The final design will be presented to previous students and the industry partner who will evaluate it, and give it a mark out of 15. This will then contribute to the final mark.

Option 5

Capacitor driven mini formula E cars. This is a new division introduced by the organisers. If enough student show interest, then this is another option for those who wish to build a car as opposed to a boat. Register you interest with the lecturer before the end of week 1.

Design project Part 1: Performance – 15%*

This will run the same as the scoring method for the boat competition.

Design project Part 2: Report – 15%*

Type: Group work**: the same group as for part 1.

Description

Students are to take on a project to develop a mechanical system and report on the outcome. The table below shows how the report will be marked.

Rubric for the report

Note that the highest mark one can get is the lowest single score of those allocated to the criteria. Therefore, you will need to ensure that all criteria are given sufficient attention.

Criterion	Pass	Credit	Distinction	High Distinction
Introduction and background	The reader understands what the report is about, why it has been written and what will follow	Plus the reader knows how success of the design project will be measured in engineering terms	As to the left	As to the left
Literature review	Theory on the key aspects of the design have been covered	Plus the theory covered is used to make decisions about the final design	Plus the review has been used to actually improve the understanding of the actual design problem	Plus the review has shown gaps in the information available, and the questions that will need to be answered during development.
Design strategy	The basic approach is communicated to	Plus it makes sense given the literature review	Plus the approach is justified by referring back to	Plus it is well argued why this is the best approach for this

	the reader and seems reasonable		the literature review	project.
System evaluation criteria	Explain the evaluation criteria for the system to be designed	Plus it makes sense given the previous 3 criteria sections	As to the left	As to the left
Concept generation	There are a number of concepts that show students considered alternatives	Plus the implications and issues of each concept are explained	Plus there is a clear diversity of ideas showing good coverage of ideas	Plus the section ends in a paragraph that explains why a good proportion of the design space has been covered
Concept selection	The method of selection is explained and a concept is chosen	Plus the selection method fits with the system evaluation method	As to the left	Plus it is used to augment and refine the concept chosen
Concept analysis	Specific and as yet unknown design variable **VALUES** are allocated with proper engineering analysis.	As to the left	As to the left	Plus the analysis is used to optimise the design appropriately.
Documentation	Drawings are done to AS1100.	As to the left	As to the left	As to the left
Conclusions and recommendations	It is clearly explained why this design is likely to be successful (refer to intro)	Plus it explains what work needs to be done to implement the design (apart from manufacture)	Plus it identifies key issues that need to be dealt with for proper implementation	As to the left
Report: Layout Completeness Quality	• The report is laid out in a sensible manner and is easy to follow. • Each part of the design is non-ambiguous and well explained or justified as required. • It has all references in a standard style. EndNote (available in the library) is recommended. • Headings are used sensibly. • Spelling and grammar are at a level that allows for sufficient ease of reading • There is a proper cover page with all needed information such as title, authors, subject details, date, informative abstract and students signatures agreeing to the contribution numbers.***			

Submission***

Each group will submit a hard copy to their tutor.

Review documents

Note that from week 7 to 8, you will also swap engineering drawings of your design with other teams (the number being equal to the number of members in your team). You will also receive one from another group. By the end of week 8 you will have to have reviewed this design (using the review document on blackboard) and emailed (CCing the lecturer and your team's tutor) the review to members of that group. If the review is not received by the tutor and lecturer, then it is not verified. These documents are not marked separately, but are essential for the assignment.

Assignment 20%

A key element of this subject is to develop an understanding of design theory and practice so that you can continue to improve as a design engineer.

Appendix XVIII

MEE 40002 Mechanical Systems Design Unit Outline 2015

Week by Week Schedule

Week	Lecture	Tutorials	Deliverable

1	Understanding design:
	• Nature
	• Ability
	• Process:
	  • Creativity/Framing
	  • First Principles
	  • Systemic thinking
		Engineering and creativity:
		• Why engineers need creativity
		• Examples from industry and students
		• Discussion on creativity and design
		Form project groups
			Read chapters 1, 2 &3 of Cross before the lecture
			Read Cross and Clayburn Cross from the printed notes before the lecture
			Take the Zimbardo Time Perspective Inventory below: http://www.thetimeparadox.com/zimbardo-time-perspective-inventory/
			Take the VAK learning style survey http://www.businessballs.com/freepdfmaterials/vak_learning_styles_questionnaire.pdf
			Submit Enter results on the respective blackboard test.
			Submit Enter group name on the respective blackboard test.

2	Doing design: Part 1 (Getting ready) • Procedures • Objectives • Functions • Requirements	Reflect upon the design attitude (how they think design should be done) of team members and the nature of the team's project. Choose a design process and have this checked by the tutor for assessment: satisfactory/non-satisfactory Work on project: creativity exercises or research	Read chapters 4, 5, 6 & 7 of Cross before the lecture
3	Doing design: Part 2 (Generating good designs) • Characteristics • Generating alternatives • Evaluating alternatives	Work on project: creativity exercises or research Project – show your plan and literature review to the tutor for assessment: satisfactory/non-satisfactory	Read chapters 8, 9, 10 & 11 of Cross before the lecture **Submit** Literature review mindmap presentation in tutorials and email to the lecturer
4	Doing design: Part 3 (Auxiliary tools) • Value engineering • Robust methods • Concurrent engineering	Project – show generation outcome and the 3-4 best alternatives to the tutorial and for assessment by the tutor: satisfactory/non-satisfactory	Read chapter 12 of Cross before the lecture Read Robust Design from the printed notes Read Concurrent Engineering from the printed notes before the lecture http://blog.grabcad.com/blog/2015/06/09/design-for-assembly/ **Submit** creativity folio
5	Managing design • Strategies • Product development	Project – explain to the tutorial which design has been chosen and what you will do to finalise it.	Read chapters 13 & 14 of Cross before the lecture Read Design for X from the printed notes before the lecture

	Design for X		
6	Risk Engineering System Reliability	Design strategy exercise (1 of the 3 on page 201 of Cross) Design for X exercises – apply two Xs to your boat	Read Risk Engineering (chapter 6 from printed notes) **Submit** Exam
7	Pressure vessels Thermal systems	Risk and reliability exercise	Download AS 1210 before lecture Read Thermal Systems in the printed notes before the lecture **Submit** Design project Swap designs with others for review
8	Motive power systems Power transmission and storage systems	Pressure vessel exercise – Lowest 't' for given volume and length Thermal system exercise – Solar balloon	Read 'Motors, Mechanical Power Transmission and Energy Storage' and 'Fluid Power' from the printed notes before the lecture. **Submit** review documents to the respective team representative, tutor and lecturer.
9	Human factors	Motive power, power transmission and storage exercise	Read 'Human Factors' from the printed notes before the lecture. **Submit** Creativity assignment
10	Design cognition Critical thinking	Human Factors exercises	Read 'Design Cognition' and 'Logic and critical thinking' before the lecture
11	Environmental noise issues	Critical thinking exercises (random activities from the text) Review boat design decisions, then analyse personal design characteristics.	Read Industrial Noise Control from the printed notes before the lecture **Submit** Exam
12	Vehicle design	Various questions on industrial noise control	**Submit** Reflective Assignment by Friday

Assessment

a) Assessment Task Details:

Tasks	Individual or Group task	Weighting	Assesses attainment of these ULOs	Assessment Due
Examination Component:	Individual	50%	1, 2, 4	Weeks 6 and 11 and exam period
Assignment Component:				
Creativity	Individual	5%	1, 4	Week 9
Reflective	Individual	15%	3	Week 12
Design project:		30%		
Prelim lit review	Group	See assessment details below	1, 2, 4	Week 3
Creativity portfolio	Group		1, 4	Weeks 4
Report	Group		1, 2, 4, 5	Week 7
Design	Group		1, 2, 4, 5	10 Oct 2015
Review	Individual		1, 2, 4	Week 8

NOTE:

- Specific assessment criteria for each assessment task can be found below in section C
- Students must retain all assessed material that contributes to the final result up until such time as the final results are published.

b) Minimum Requirements to pass this Unit of Study:

To pass a Faculty of Engineering and Industrial Sciences (FEIS) units, you must achieve:

i. at least 35% of the possible final marks for each Major Assessment Component plus
ii. an aggregate mark for the subject of 50% or more.
iii. any other minimum requirements to pass the unit, including participation requirements

If you do not achieve at least 35% of the possible final marks for each Major Assessment Component you will receive a maximum of 44% as your mark for the subject concerned.

c) Submission Requirements:

Design project 30%*

Type: Group work** (3-4 members). For option 1 one member (and one only) must be a non-mechanical engineering student (single or double degree) and at least 2 need to be mechanical. Additionally, each group must have at least one member that has a significant international element. It could be an international student or a student who spent considerable time in another country. The non-mechanical student can also be the student with an international element. Finally, each group needs at least 2 local students. These requirements are to expand your exposure to different design attitudes as much as possible.

Groups must be formed by the end of week 1.

The design task is explained in the relevant document on blackboard. Note that the key element of the task is that will require the combined knowledge of prior engineering science subject and that the solution is not obvious. You will need to further refine the problem to be solved, use engineering science theory to better understand it (and solve it) and develop what will likely be a unique solution. Finally, the assessment of the design will include its operations; therefore, the design will need to be easily and safely operated.

Performance mark – 15%*

Type: Group work**

Description

The culmination of the design will be assessed for performance. The manner in which the performance is measured and then converted to a mark is explained in the respective document on blackboard.

Report mark – 15%*

Type: Group work**

Description

Students are to take on a project to develop a mechanical system and report on the outcome. The table below shows how the report will be marked.

Submission***

Each group will submit a hard copy to their tutor.

Rubric for the report

Note that the highest mark one can get is the lowest single score of those allocated to the criteria. Therefore, you will need to ensure that all criteria are given sufficient attention.

Criterion	**Pass**	**Credit**	**Distinction**	**High Distinction**
Introduction and background	The reader understands what the report is about, why it has been written and what will follow.	Plus the reader knows how success of the design project will be measured in engineering terms.	As to the left	As to the left
Literature review	Theory on the key aspects of the design has been covered and it aligns with the mind map of week 3, which was marked satisfactory.	Plus the theory covered is used to make decisions about the final design.	Plus the review has been used to actually improve the understanding of the actual design problem.	Plus the review has shown gaps in the information available, and the questions that will need to be answered during development.
Design strategy	The basic approach is communicated to the reader and seems reasonable.	Plus it makes sense given the literature review.	Plus the approach is justified by referring back to the literature review.	Plus it is well argued why this is the best approach for this project.
System evaluation criteria	Explain the evaluation criteria developed for the system to be designed.	Plus these makes sense given the previous 3 criteria sections.	As to the left	As to the left
Concept generation – brain storming	There are a at least 3 ideas per member showing diversity and extension upon the folio presented in week 4.	Plus the implications and issues of each concept are explained.	Plus there is a clear diversity of ideas (from affinity analysis) showing good coverage of ideas.	Plus the section ends in a paragraph that explains why a good proportion of the design space has been covered.
Concept selection	The method of selection is explained and a concept is chosen.	Plus the selection method fits with the system evaluation criteria.	As to the left.	Plus it is used to augment and refine the concept chosen.
Concept analysis	Specific and as yet unknown **design** variable **VALUES** are allocated with proper engineering analysis and modelling.	Plus the analysis is used to optimise the design appropriately.	Plus the modelling includes the entire system (hydrodynamics and electrical system for example).	Plus the analysis is used to optimise the performance.
Documentation	Drawings are done to AS1100 and all parts are detailed well enough for production and verification.	As to the left.	As to the left.	As to the left.
Conclusions and recommendations	It is clearly explained why this design is likely to be successful (refer to intro).	Plus it explains what work needs to be done to implement the design (apart from manufacture).	Plus it identifies key issues that need to be dealt with for proper implementation.	As to the left.
Report: Layout Completeness Quality	• The report is laid out in a sensible manner and is easy to follow. • Each part of the design is non-ambiguous and well explained or justified as required. • It has all references in a standard style. EndNote (available in the library) is recommended. • Headings are used sensibly. • Spelling and grammar are at a level that allows for sufficient ease of reading • There is a proper cover page with all needed information such as title, authors, subject details, date, informative abstract and students signatures agreeing to the contribution numbers.***			

Prelim lit review

Type: Group work**

In week 3 teams will need to present a mind map that summarises the literature that has been reviewed. The mind map should:

1. Include the major topics pertinent to the project
2. Break the topics down into ley sub-topics
3. Note the areas where the research community is in agreement and areas where this is still research ongoing or needed
4. Cite the source of each major point
5. Note decisions that have been made about the design from the literature
6. Note the design challenges identified after reading the literature

The mind maps will be presented in the tutorial and marked either satisfactory (having the above 6 items) or not satisfactory. It will need to be satisfactory to pass the respective section of the report.

Creativity portfolio

Type: Group work**

In week 4 teams will need to present their creativity portfolio to the tutor in the respective tutorial. This is the foundation for the respective section in the report, and must be submitted so that the report can be marked at a later stage.

Students will present the folio in the tutorial and email a scan of the portfolio to the tutor for verification when marking the report.

The portfolio will be marked in accordance with the following rubric to provide feedback for the later report and creativity assignment.

Criterion	Pass	Credit	Distinction	High Distinction
Use of space	An A3 folder is used and each idea is given at least one page for expansion	Plus ideas that are conceptual are expanded in graphic form to enhance words	Plus the space is used to show details, sections and develop specific aspects so that a full understanding of the idea is had	
Idea diversity	There are at least 3 different aspects to the problem considered	Plus there are 3 distinct possible solutions for each aspect	Plus, common themes are used produce ideas of slightly different nuance	Plus, common themes are used to consider completely different themes
Idea quality	Ideas at least align with the challenge	Plus ideas are developed within an understanding of theory		Plus some ideas appear to be unique amongst prior art
Idea evaluation development	Ideas are evaluated for basic viability using established theory	Plus ideas are evolved to account for limitations that have been identified	Plus ideas of different themes are brought together to develop ideas further	Plus theory is used to reframe the problem and redirect creative efforts

Review assignment

Type: Individual work**

Description

Note that from week 7 to 8, you will swap engineering drawings of your design with other teams (the number being equal to the number of members in your team). You will also receive one from another group. By the end of week 8 you will have to have reviewed this design (using the review document on blackboard) and emailed (CCing the lecturer and your team's tutor) the review to members of that group. These documents are foundations for the creativity assignment and the reflective assignment: you will need the reviews to ensure that you can get solid marks for these pieces of assessment. Below is a guide to what makes for a good review.

Pass	Credit	Distinction	High Distinction
The reviewer has taken the time to understand the design and this is evident.	Plus the reviewer has made suggestions that will help improve the design.	Plus the issues raised show an appropriate understanding of the pertinent engineering science theory.	Plus the reviewer raises issues that relate back to how the problem has been framed and comments accordingly (positive or negative)

Assignment – creativity

Type: Individual work**

Between finalising the report and implementing (making) the final design, you will encounter a number of unforeseen problems that will require a solution. To improve your creative ability, you are expected to use it to solve one of these identified problems. While you might work on this with your group, you will be expected to report upon the problem and the solutions as an individual. For this assignment you need only:

1. identify the problem,
2. cover the tools you used to investigate it creatively and the results of their implementation,
3. explain how you went about selecting the solution and
4. present the solution chosen.

The report will be marked subjectively based upon how well you have gone about the above and how well you have documented it. This will be done within the context of how creativity was marked earlier so be aware of the feedback you have gotten from previous creativity assessment.

Assignment – Reflective 15%

Type: Individual work**

Description

A key element of this subject is to develop an understanding of design theory and practice so that you can continue to improve as a design engineer.

To demonstrate this understanding, you will need to convince the reader that you have a well formulated and practical plan to be an expert design engineer in 10 years.

You will do so via a 1500 (max with review documents on their design and others as an appendix) reflective document. It should be written in a style suitable to reflection; this will be covered in class; however, you may wish to read over the related document posted on Blackboard under learning material titled 'How to write a reflective piece'.

You will be marked based on the rubric below and given the average of the outcomes as your final mark for this assignment.

Appendix XIX

MEE30003 Machine Design Unit Outline 2015

PART B Your unit in more detail

Ongoing Unit Improvements

Based on student and staff feedback collected when this unit was last offered, the Unit Panel has implemented the following improvements and updates:

- Students need to be informed that this subject is about recalling and applying theory already taught. Many student questions might be answered with other questions to encourage this ability. Do not be surprised if this is a challenge for you. However, do try to shift your thinking if you need to. Please also note that this is the reason why some questions will not be answered directly when you expect them to be.
- Last year, students found the weekly tests along with the first submission of the gearbox design (phase 1) demanding. The designs were excellent, but the tests did not go well. This year the tests can be done when the student wishes as long as they are done by the 4th of June. This should allow for more flexibility in time management.
- Tutorials will now be run in two parts. One for the weekly topic and one for the design project. This will ensure that all students get a chance to cover what they need to cover.

Teaching Staff

Name	Role	Campus & Room No.	Phone No.	Email Address	Consultation Times

This part is covered due to the confidential information.

Learning and Teaching Structure

Lectures will be broken into two sections. The first will focus on the topic of that week. It will cover the key aspects that are important about that topic. This is to ensure that as an engineer, you are aware of machine elements and how they work. The second half is dedicated to improving your ability to apply theory to machine element analysis. This is so that you can use theory to model and optimise your designs. The tutes too will be in two parts. One is for the weekly topic to cover off questions that you have and another for progressing your design project.

Teaching Activity	Total Hours	Hours per Week	Semester Weeks
Lectures	24 hours	2 hours	Weeks 1 to 12
Tutorials	24 hours	2 hours	Weeks 1 to 12

In a Semester, you should normally expect to spend, on average, twelve and a half hours of total time (formal contact time plus independent study time) a week on a 12.5 credit point unit of study.

Week by Week Schedule

Wk	Lecture	Tutorials	Deliverable
1	Introduction to subject and assessment Modelling versus calculating Dimensionality and bastard equations Creativity in engineering design	Modelling versus calculating See exercises on blackboard	Form groups Email group details to tutor (names, ID, courses, leader/contact person)
2	Gears: Spur, helical, bevel and worm gears: geometry, gear-tooth stresses, design approaches for compact housings of gear trains	Modelling versus calculating Creativity tool	Review Test 1 and read chapter 15 and sections 16.1, 16.2, 16.3, 16.6, 16.9 &16.10 before lecture Summarise key theory and initial ideas
3	Shafts: Design, mounting of parts, connections, support, coupling.	Gears	Review Test 2 and read Chapter 17 before lecture Show proposal to tutor and discuss
4	Sliding bearings: Viscosity; Petroff's equation; Thin film flow; Hydrostatic bearings; Hydrodynamic bearing theory; Tilting pad and thrust bearings.	Shafts	Review Test 3 and read Chapter 13 before lecture Show refinement of ideas to tutor
5	Rolling element bearings: Types, design, fitting, selection	Sliding bearings	Review test 4 and read Chapter 14 before lecture Submit drawings for review
6	Belts and chain drives: Flat, vee, and toothed belts; Roller and toothed chains.	Rolling element Bearings	Review test 5 and read 18.9, 19.2, 19.3, 19.4 and 19.5, before lecture. Submit review documents
7	Clutches and brakes: Disk, drum and band brakes; Disk and cone clutches	Belts and Chains	Review test 6 and read Chapter 18 before lecture Show tutor planned responses to reviews
8	Cams and flywheels: Cam terminology; Output functions; Cam design: profiles, sizing, manufacture, followers, crank effort diagrams, sizing flywheels.	Clutches and brakes	Review test 7 and read chapters 1 & 2 of Jensen before lecture Read chapter 5 of Hannah and Stephens Show tutor revised proposals
9	Energy storage: Mechanical energy storage: elasticity and deflection, inertia; Design, selection and application of torsion bars, helical and leaf springs; Design for impact: absorbing energy, impact.	Cams and flywheels	Review Test 8 and read Chapters 12 and 7 before lecture Cover latest design issues with the tutor and plans to resolve these
10	Tolerances: Tolerances for assembly; Statistical tolerancing; Tolerance build-up. Shafts and holes.	Springs	Review test 9 and read tolerances chapter from Boundy & read up on IT Grade before lecture Communicate progress and challenges to the tutor with corrective plans
11	Fasteners and joints: Threaded fasteners: types, capacity, selection, installation; Joints and gaskets: types of seals, gaskets and fastening stresses; Rivets, welding and bonding: selection, stress and fatigue considerations.	Gear box tests	Review test 10 and read Chapters 10 & 11 before lecture
12	Modelling and derivation	Fasteners	Project report Read Chapter 16 of Otto and Wood before lecture

Assessment

a) Assessment Overview

Types	Individual or Group task	Weighting	Assesses attainment of these ULOs	Due Date
Examination	Individual	40%	1, 2, 4	Exam Period
Test(s)	Individual	10%	1	4th June 24:00
Design Performance	Group	20%	1, 2, 3, 4	Week 11 tutorial
Project Reports	Group	30%	1, 2, 3, 4	Week 12

b) Minimum requirements to pass this Unit

To pass a Faculty of Science, Engineering and Technology (FSET) unit, you must achieve:

- achieve at least 35% of the possible final marks for each Major Assessment Component (any assessment worth 15% or more), and
- achieve an aggregate mark for the subject of 50% or more, and
- achieve at least 45% in the final exam

If you do not achieve at least 35% of the possible final marks for each Major Assessment Component and at least 45% for the final exam, you will receive a maximum of 44% as your total mark for the unit.

c) Examinations

If the unit you are enrolled in has an official examination, you will be expected to be available for the entire examination period including any Special Exam period.

d) Submission Requirements

Assignments and other assessments must be submitted through the Blackboard assessment submission system (Turnitin).

Please ensure you keep a copy of all assessments that are submitted.

An Assessment Cover Sheet must be submitted with your assignment. The standard Assessment Cover Sheet is available from the Current Students web site (see Part C).

e) Extensions and Late Submission

Late Submissions - Unless an extension has been approved, you cannot submit an assessment after the due date. If this does occur, you will be penalised 10% of the assessments worth for each calendar day the task is late up to a maximum of 5 days. After 5 days a zero result will be recorded.

f) Referencing

To avoid plagiarism, you are required to provide a reference whenever you include information from other sources in your work. Further details regarding plagiarism are available in Section C of this document.

Referencing conventions required for this unit are up to you, but must be consistent.

Helpful information on referencing can be found at
http://www.swinburne.edu.au/lib/studyhelp/harvard-quick-guide.pdf

g) Groupwork Guidelines

Note the requirements stipulated in the 'Assessment details' section.

h) Assessment details

Design project 50%

Type: Group work* (3-4 members). At least one member must be a non-mechanical engineering student (single or double degree). Additionally, each group must have at least one member that has a significant international element. It could be an international student or a student who spent considerable time (2+ formative years) in another country. Finally, the group must have at least 2 mechanical engineering students and at least 2 local students.

The non-mechanical student can also be the student with an international element.

These requirements are there to expand your exposure to different design attitudes as much as possible.

Groups do not need to be within the same tutorial although it is advised that they are. However, the group will need to nominate a leader who communicates with the tutor and lecturer regarding issues for this project. The tutorial that the leader is in will be viewed as the group's official tutorial and will be the tutorial that all assignments are handed in at.

Description

Option 1 – gear box design and build

Student teams are to design and build from laser cut acrylic sheet and rod a gearbox. The gearbox will be used to lift a weight (to be specified by the student team, but at least 8kg) a height (also specified by the student team, but no greater than a standard tute room table and greater than 100mm) as quickly as possible.

The gearbox will be powered by a standard electric motor. The details of the motor can be found on blackboard.

Requirements

1. The only material that can be used other than acrylic is glue to hold the parts together and string or cord to attach the sled.
2. The gearbox will need to be secured. This will be done using the studs on the board and nuts. See the drawing of the board on blackboard for more details.

Allocated resources

Laser cutting

Each team can get 1 A4 sheet sized drawing laser cut into any number of parts that they can fit on it. To do this, the file will need to be emailed to your tutor (when you submit your drawings for review). The file will need to be a dxf file and the file name will need to include your name and your phone number so that the technician can call you up when your parts are ready.

You can cut as many other parts out of your own acrylic as you wish. It would be wise to save the more precise parts for the laser cutting. You might also want to make all your parts by hand first to test them and then have them made more accurately with the laser cutter. However, you can get a first run cut in week 6 (you will need to have the dxf files to your tutor by the end of week 5) and the final set cut in week 9 (the dxf files will need to be to your tutor by the end of week 8).

Note:

The speed of production will depend upon how busy the workshop is. It will be first come first served. Also, things can go wrong – technicians get sick and machine break – if something does delay production, then we will deal with it at that time.

The dxf files must be of what you want cut and nothing else. Any dimension lines or centre lines will also be cut.

If you want to know more about working with acrylic, then take a look at the links below.
http://www.abplastics.com.au/hintsandtips/acrylics/index.php
http://en.wikipedia.org/wiki/Poly(methyl_methacrylate)

CAD

It is advised that you use SolidWorks to design your gearbox. An example of how a gear can be designed in SolidWorks can be seen on Blackboard.

Part 1: performance – 20%

The performance *p* of the gearbox will be based on the formula below:

$$p = \frac{mgh}{t\,V\,I}\frac{mgh}{t\,D^3}$$

Where: *m* is the mass lifted, *g* is acceleration from gravity, *h* is the height the weight is lifted, *t* is the time taken and *D* is the maximum axial length of the gearbox, *V* is the voltage applied while lifting and *I* is the current drawn while lifting. Note – excessive set up time will result in a *p* of zero.

It should be clear that this is a measure of power to volume by efficiency.

The score *s* allocated to each team is based on the following formula

$$s = \frac{(p - p_{min})}{(p_{max} - p_{min})} 10\% + 10\%$$

Where: p_{min} is the lowest performance achieved within the subject and p_{max} is the highest performance achieved within the subject.

The score for part 1 is dependent upon how a team performs relative to the rest of the teams.

Part 2: Report** – 30%

Each team will need to submit a report that details the design with suitable drawings, explains the key design decisions, documents the modelling and calculations used to set key design parameters and reviews the performance of the design.

The marking rubric is shown below; this would also make a good guide for the report layout.

Design reviews

Note that the report includes reviews of other designs and reviews of your design by students outside of your group. This is to provide 'market research' and to give you guidance on improving your design.

On week 5, when you submit your initial design for a cut, you will also submit engineering drawings of your design. Your drawings will be distributed to other students (the number will be equal to the number of students in your group). You will also receive one from another group. By the end of week 6 you will have to have reviewed this design (using the review document on blackboard) and emailed (CCing the lecturer and your team's tutor) the review to members of that group. If the review is not received by the tutor and lecturer, then it is not verified.

This will then affect the marking of the report. See below and note the need for complete initial designs to be submitted in week 5.

Only people who have submitted drawings will be given drawings to review. Thus, if you do not have drawings to submit, you will end up receiving zero for that section of the report.

Rubric for the report

The table below shows how the report will be marked. Note that the mark given is the highest of the lowest grade the report scores in any of the criteria. Therefore, ensure that all criteria are given sufficient attention.

Criterion	Pass	Credit	Distinction	High Distinction
Introduction	The reader understands what the report is about, why it has been written and what will follow	As to the left	As to the left	As to the left
Literature review	Theory on the key aspects of the system to be designed has been covered	Plus the theory covered is used to make decisions about the final design	Plus the review has been used to actually improve the understanding of the actual design problem	Plus the review has shown gaps in the information available, and the questions that will need to be answered during development.
Design approach/ strategy	The basic approach is communicated to the reader and seems reasonable	Plus it makes sense given the literature review	Plus the approach is justified by referring back to the literature review	Plus it is well argued why this is the best approach for this project.
Creativity (note – sketches will be useful here)	A problem requiring creativity is clearly identified	Plus the reason why this problem needs creativity is needed is explained well	Plus a number of diverse ideas as defined by affinity analysis is apparent	Plus ideas are developed further and weaknesses of ideas are corrected to ensure thoroughness.
Modelling and calculating	Theory is applied correctly and used to determine key design variable values.	As to the left	As to the left	Plus the modelling is used to optimize the design in accordance with the goals.
Market research	There is a verified and completed review of another design for each group member	Each review shows an understanding of the pertinent theory	The reviews are used to evaluate the design the group has produced.	As to the left
Response to external review	All the expected reviews of the <u>complete</u> initial design are present	The changes to be made in response to the reviews are listed and properly justified	As to the left	As to the left
Documentation	Drawings meet AS1100.	As to the left	As to the left and drawings can be used to make the system designed	As to the left
Reflection	The performance of the design is considered and explained with regards to the design.	As to the left	Plus how the chosen design strategy resulted in the performance is well argued.	Plus changes in the team (management and design practice) for better performance next time are well argued.
Report:** **IMPORTANT**	Laid out sensibly; presented professionally (bound); all references are in a standard style (EndNote - available in the library - is recommended); spelling and grammar allow for ease of reading; a proper cover page with title, authors, subject details, date, informative abstract and students signatures agreeing to the contribution numbers.^			

Appendix XX

DPD20002 Product Design Engineering Studio Unit Outline 2015

PART A: Unit Summary

Unit Code(s)		DPD20002
Unit Title		Product Design Engineering Studio
Duration		12 weeks
Total Contact Hours		48 hrs per semester
Requisites:		
	Pre-requisites	DPD10001 Product Design Studio 1, DPD10002 Product Communication, DPD10003 Product Design Studio 2
	Co-requisites	Nil
	Concurrent pre-requisites	Nil
	Anti-requisites	Nil
	Assumed knowledge	
Credit Points		12.5
Campus/Location		Hawthorn
Mode of Delivery		Face-to-face
Assessment Summary		Design Studio - 45%-65% Sketching Folio - 20%-25% Digital Visualisation Folio - 20%-25%

Aims

This unit of study aims to have you:

- Develop a range of product design and development skills, including innovative idea generation, visualisation skills and implementation of engineering methodologies. Apply reverse engineering as a technique for understanding and exploring internal product complexity. Appreciate Product Design Specifications as a method of managing the documentation of complex product design requirements. Demonstrate consideration of user demographic and cultural contexts in product design practices.
- Use quick sketching techniques to cover approaches for communicating external and internal product detail and digital visualisation techniques for photo manipulation, page layout and product design presentation.

Unit Learning Outcomes

Students who successfully complete this Unit should be able to:

1. Apply practical engineering methodologies, such as reverse engineering processes, to determine effective and efficient design.
2. Apply idea generation techniques and consider user demographics to achieve innovative and appropriate product design outcomes.
3. Interpret internal and external product requirements and generate product design specifications.
4. Address a range of product design and development skills including engineering documentation, CAD techniques and prototyping into design projects.
5. Use and appropriately select sketching techniques to effectively communicate design intent.
6. Use computer image enhancing and digital presentation techniques to visually communicate design and engineering intent.

Key Generic Skills

This Unit of Study will contribute to you attaining the following Swinburne Engineering Competencies:

Emerging Disciplinary Trends: Interprets and applies current or emerging knowledge from inside and outside the specific discipline.

Practice Context: Discerns and appreciates the contextual factors affecting professional engineering practice.

Engineering Methods: Applies engineering methods in practical applications.

Problem Solving: Systematically uses engineering methods in solving complex problems.

Design: Systematically uses engineering methods in design.

Project Management: Systematically uses engineering methods in conducting and managing projects.

Ethics: Values the need for, and demonstrates, ethical conduct and professional accountability.

Communication: Demonstrates effective communication to professional and wider audiences.

Entrepreneurial: Appreciates entrepreneurial approaches to engineering practice.

Information Management: Demonstrates seeking, using, assessing and managing information.

Professional Self: Demonstrates professionalism.

Management of Self: Demonstrates self-management processes.

Teamwork: Demonstrates effective team membership and team leadership.

Content

This unit is comprised of three delivery modules, covering the following content:

1. Design Studio
This component will continue to build on a range of product design and development skills
- Concept development and design methodology
- Engineering documentation
- Basic principles of product design specifications
- Material, Processes and assembly techniques
- Reverse engineering processes
- Analysis of product reliability, performance and complexity
- Ergonomic principles and analysis of product semantics
- Research user demographics

2. Illustration / Sketching
This component is to further develop quick sketching techniques to proficiently communicate design and engineering intent and develop product design ideas:
- Accurate perspective creation
- Techniques for sketching internal product detail
- Explanatory and exploratory sketching techniques

3. Digital Visualisation
This component enables students to create digital presentations of their designs through the use of digital communication software including:
- Introduction to Adobe software;
- Photo-manipulation
- Vector-based content creation
- Page layout and presentation techniques.

PART B: Your Unit in more detail

Unit Improvements

Feedback provided by previous students through the Student Survey has resulted in improvements that have been made to this unit. Recent improvements include:

- Improvement in the assessment methods and balancing of student workloads

Unit Teaching Staff

Name	Role	Room	Phone	Email	Consultation Times
This part is covered due to the confidential information.					

Learning and Teaching Structure

Activity	Total Hours	Hours per Week	Teaching Period Weeks
Design Studio	30 hours	2.5 hours	Weeks 1 to 12
Illustration Tutorials	9 hours	1.5 hours	Weeks 1 to 6
Digital Vis. Tutorials	9 hours	1.5 hours	Weeks 7 to 12

Preparation requirements:
All classes are studios working environments. Students will be expected to attend for the scheduled duration of the class and use the time productively to further their design projects/skill development and participate in class activities.

Students must come to class prepared, with current project work, appropriate materials such as sketch pads, drawing equipment (pens, markers, rulers, etc), workshop safety equipment as required (glasses, appropriate footwear and attire, respirator masks, etc), digital imagery and digital storage devices.

Assessment Details

Week by Week Schedule

Design Studio

	Your class time	Content
Wk1	Monday 2 March	**Introduction**: unit outline review previous projects **Briefing**: Project 1 'spork' Class work: review projects, design exercises, Demographic research
Wk2	Monday 9 March	**DUE: research.** pin up Class work: concept generation Info delivery: injection moulding details, split lines, Layout methods and details

Wk3	Monday 16 March	**DUE: 3XConcept Panels** Class work: Cad modelling Info delivery: Eng layout, snapfit calculations
Wk4	Monday 23 March	**DUE: Final Concept Illustration panels** **Final mock-up and initial calculations**
Wk5	Monday 30 March	**Project 1: Final presentation (submit all deliverables)** Briefing: project 2 'inside out' target market category, teams formed
	EASTER BREAK: Thursday 2 April - Wed 8 April (inclusive)	
Wk6	Monday 13 April	**Project 2 DUE:** Target Market research, BOM analysis **BRING TO CLASS:** product to reverse engineer, tools – pliers, etc to aid in reverse engineering analysis.
Wk7	Monday 20 April	**Project 2 DUE:** technical report, PDS & user group research
Wk8	Monday 27 April	**Project 2 concept presentation**
Wk9	Monday 4 May	**Project 2** Design development. **Due: Blue foam mock-ups.**
Wk10	Monday 11 May	**Review: final direction.** Informal pin up - design development
Wk11	Monday 18 May	Review CAD and documentation
Wk12	Monday 25 May	**Project 2: final presentation (submit all deliverables)**

Illustration and Digital Visualisation

	Your class time	**Content**
Wk1	Friday 6 March	**Introduction**: subject outline review previous projects Perspective construction (line drawing)
Wk2	Friday 13 March	Quick marker techniques
Wk3	Friday 20 March	Exploration of form
Wk4	Friday 27 March	Explanatory sketching (annotation, directional arrows, showing how things work)
	EASTER BREAK: Thursday 2 April - Wed 8 April (inclusive)	
Wk5	Friday 10 April	Internal product detail
Wk6	Friday 17 April	Exploded view, Illustration tutorials concludes. Submit All sketches in A3 Folio

Wk7	Friday 24 April	**Note new room for Digital Vis.** Introduction to Illustrator – Basic Tutorial Begin Task 1.1 – Logo Design
Wk8	Friday 1 May	Bring to Class: Min. 2 A3 pages of logo concept sketches Working on Task 1.1 in Illustrator
Wk9	Friday 8 May	Bring to Class: Completed Task 1.1 Introduction to InDesign Brief Task 1.2 – Presentation Panels
Wk10	Friday 15 May	Bring to Class: Min. 2 A3 pages of logo concept sketches Working on Task 1.2 in InDesign
Wk11	Friday 22 May	Bring to Class: Completed Task 1.2 Introduction to Photoshop Brief Task 2 – Image Manipulation
Wk12	Friday 29 May	Bring to Class: Product Photo/Rendered Image + Background Image Working on Task 2 in Photoshop/InDesign
Wk13	Friday 5 June	Submit all deliverables for Digital Visualisation Task 1.1, 1.2 & Task 2 no later than 5pm Friday Week 13 on blackboard as detailed in the brief

Assessment

a) Assessment Overview

Tasks and Details	Individual or Group	Weighting	Unit Learning Outcomes that this assessment task relates to	Assessment Due Date
1. Design Studio-Minor Project	Individual	21%	K4,K5,S1,S2, A2,A4,A5,A6,A7	Progressive & Week 5
2. Design Studio –Major Project	Group	39%	K4,K5,S1,S2,S3,S4 ,A2,A4,A5,A6,A7	Progressive & Week 12
3. Illustration Folio	Individual	20%	K4,S1, S2, S3, A2	Progressive & Week 6
4. Digital Visualisation	Individual	20%	K4,S1,S2,S3,A2	Progressive & Week 13

b) Minimum requirements to pass this Unit

To pass this unit, you must:

- demonstrate that you have satisfactorily achieved the aims and learning objectives of the unit
- gain a minimum of 50% in assessment tasks for all 3 areas of content: design studio, sketching/illustration and digital visualisation.

c) Examinations

Not Applicable.

d) Submission Requirements

Visual assessment and similar artefacts should be submitted according to instructions provided by the Unit Convenor. Written assignments and other assessments must be submitted through the Blackboard assessment systems.

Please ensure you keep a copy of all projects and assessments that are submitted.

An Assessment Cover Sheet must be submitted with your assignment. The standard Assessment Cover Sheet is available from the Current Students web site (see Part C).

e) Extensions and Late Submission

Late Submissions - Unless an extension has been approved, you cannot submit an assessment after the due date. If this does occur, you will be penalised 10% of the assessments worth for each calendar day the task is late up to a maximum of 5 days. After 5 days a zero result will be recorded.

f) Referencing

To avoid plagiarism, you are required to provide a reference whenever you include information from other sources in your work. Further details regarding plagiarism are available in Section C of this document.

Referencing conventions required for this unit are: Harvard Style Referencing

Helpful information on referencing can be found at
http://www.swinburne.edu.au/lib/studyhelp/harvard-quick-guide.pdf

g) Groupwork Guidelines

A group assignment is the collective responsibility of the entire group, and if one member is temporarily unable to contribute, the group should be able to reallocate responsibilities to keep to schedule. In the event of longer-term illness or other serious problems involving a member of group, it is the responsibility of the other members to immediately notify the Unit Convenor or relevant tutor.

Group submissions must be submitted with an Assignment Cover Sheet, signed by all members of the group.

All group members must be satisfied that the work has been correctly submitted. Any penalties for late submission will generally apply to all group members, not just the person who submitted.

A personal and group assessment form will be submitted with each group assignment and if required, used to moderate assessment allocation.

Required Textbook(s)

Recommended Reading Materials

The Library has a large collection of resource materials, both texts and current journals. Listed below are some references that will provide valuable supplementary information to this unit. It is also recommended that you explore other sources to broaden your understanding.

Byars, M 2004 *The Design Encyclopedia,* New York, Museum of Modern Art & Laurence King.

Datschefski, E 2001 *The Total Beauty of Sustainable Products*, Rotovision, Switzerland.

Forty, A 1992 *Objects of Desire: Design and Society Since 1750*, Thames & Hudson, London.

Friell, C & P *Industrial Design A – Z*, Taschen Germany,

Hauffe, T 1998 *Design,* Laurence King, London.

Sparke, P 1998 *A Century of Design: Design Pioneers of the 20th Century*, Mitchell Beazley London.

Swinburne School of Design

Bachelor of Engineering (Product Design Engineering)

Quality Learning, Innovative Research

DPD20002 Product Design Engineering Studio, Semester 1, 2015

'spork'

Contributes 35% to Design Studio marks

source: www.gizmodo.com.au

source: shop.walkerart.org

source: www.ultralightoutdoorgear.co.uk

Design brief details:

Using the design and analysis of small plastic components you will be designing a group of **cutlery** for a defined demographic. The cutlery should **provide the range of functions as used in a fork, spoon and knife.** You must be able to cut some meat (eg. Sausage, but not thick steak), spear food and capture small amounts of liquid (eg soup – spoon).

You will define the **target market** from children, elderly or camping enthusiasts. The design must be compact, light weight **and design must not exceed an envelope of 150 x 30 x 30 mm when compacted**. Using a plastic **'snap'** fit all components must connect together when the product is not in use so that no pieces can get lost. Your design cannot just have a rubber band or Velcro strap as a solution to this parameter!

The **material** your cutlery design must use is plastic. The plastic component/s must be **manufactured** using plastic injection moulding. You may also use other materials for small, minor components, e.g. a spring, pin or metal piece as a complementary material. You may also use 'over moulding' as part of the plastic injection moulding piece/s.

consider:

- Ergonomics in use of cutlery – ease of gripping handle, ease in assembling from space saving form and compacting back for storage, loading cutlery with food.
- Ease of cleaning to reduce crevices where food can build-up
- Safety when using (limit sharp edges on fork or spoon area) or when folding and the protection from other items in storage
- Cultural issues including the way other cultures prepare, cook and share food
- Material thickness and strength when applying pressure to food to cut and spearing
- Visuals and packaging that suit your demographic

stages:

1) **Research:**

A diverse 'User research' is critical to the understanding of customer requirements and the 'boundaries' that designers are required to define. Document existing products as well as complimentary products in other industries, for camping cutlery you may look at other camping products, rock climbing products/materials. Review the latest materials and manufacturing processes.

Research the ergonomics/user interaction with cutlery (gripping handle, food loading, left and right handed) and different types of materials, textures and eating utensils. Explore different cultures when investigating different types of cutlery and ways of utensils delivering food into your mouth. Conduct first hand research (spoon, knife, fork and AT LEAST 1 alternative eating utensil) and document with camera!
Generate:

- 1 x A3 panel that looks at different cultures and alternative ways of eating using utensils, evidences 1st hand research.
- 1X A3 panel that defines you chosen demographic, use images that would be associated with their lifestyle, other products they may use/ purchase, define if they are high end or low margin consumers
- 1 x A3 panel - review new and novel cutlery designs
- 1:1 drawing of 1 style of cutlery with overall dimensions (A3 size) – knife, spoon and fork (to gain an understanding of appropriate product scale)

'A3 panels' do not need to be mounted – they should be printed that can be **pinned up for review** and later added to your folio. Analysis must be accurately referenced, list photo sources and include observation/use of camping cutlery.

2) concept generation. Brainstorm eating and space saving mechanisms to keep the cutlery compact. Sketch as many ideas as possible for your chosen demographic cutlery designs. Produce a minimum of **8 -10 A3 concept** pages filled with a good breadth and depth of ideas (at least 6 fundamentally different ideas - absolute minimum!) Bring samples to class of other products that clip together. Sketch fingers and hands on the product that represent scale. Layout the pages professionally showing a flow of idea development.

Generate and Present 3 x A3 Concept panels (3 different designs in week 3) in the concept review. For each A3 concept you should have a perspective sketch (hand rendered to show form, colour and any texture), a 1:1 front side elevation view, and an accompanying descriptive/explanatory sketch that demonstrates a detail integral to your design, e.g. Snap fits, sectional views, how the cutlery compacts, how you hold/use it, etc.

3) concept refinement. 1 concept will be selected in week 3 for refinement.
Using detailed sketches explore the detail of the design using sectional views and exploded sketches, explore snap fit alternatives, plastic die moulding details. **4-6 pages Minimum**
You will perform calculations on the 'main' plastic component to determine design details. (there will be further assistance/guidance on this deliverable). Adjust design according to these initial calculations – thinner or thicker profiles, etc. Make sure you have a final set of calculations that justify the end dimensions/shape of your design.

Generate 1XA3 Final Concept Illustration that defines all the features for your chosen demographic.
You will generate a blue foam form study to evaluate ergonomics/operation(other materials are ok for mock-up depending on design – but NOT all plasticine).

4) final documentation. From your Final Concept Illustration create a CAD model in Solidworks of your cutlery design. From this you will produce:

CAD generated technical drawings:
An assembly orthogonal view with overall dimensions (so front, top, side and iso view)
An exploded view with BOM
A cross section view with details (in particular on the snap fit and hinging)
A **fully dimensioned drawing** of **one part only**, all sections and details dimensioned

- Final Calculations with sketches showing flex & bending, tooling split line ect.
- Rapid prototyping from .stl files using Cube printers (is acceptable)

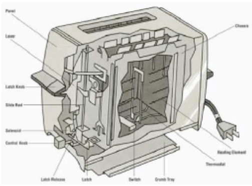
5) final presentation Present a summary of all the stages of your final design.
Load onto Blackboard 1 hour before class commences. Presentation (maximum of 3 minutes) to be succinct and planned covering demographic, concepts, final concept illustration, assy & BOM, detailed engineering drawings and calculations (with enlarged sketches/details)

Swinburne School of Design

Bachelor of Engineering (Product Design Engineering)

Quality Learning, Innovative Research

DPD20002 Product Design Engineering Studio, Semester 1, 2015



project 2: 'inside out'

65% design studio marks

brief details:

In Groups of 2, you will be reverse engineering and re-designing a consumer product from the following:

- Food processors, Choppers
- Hair dryer
- Electric hand blender, electric mixer/beater
- Electric drill or electric hand sander
- Toaster
- Shaver
- Electric Battery Can opener

(approval from the tutor needs to be provided to ensure appropriateness of product selection)

You will need to source a product for reverse engineering – most of the products listed have options available for approximately $20 for 'no name' brands. Your re-design will be according to a specific target market your group will be assigned.

Important: Before you disassemble the product you MUST cut off the electrical plug and never use or reassemble the unit for future operation.

background:

Consumer products are often presented to us as objet d'art, must-have appliances loaded with new (and apparently essential) features, bristling with new technology and catering to our every need - functional machines dressed as fashion. But are they the products we need?

- Do they address our user requirements, our ergonomic needs and safety concerns? Do they address the needs of **all** users?
- Do they truly represent an improvement in our quality of life?
- Are they well made, reliable and functional?
- Are they material and labour efficient in their construction and assembly?
- Can the individual components be easily disassembled and separated for recycling at the end of the product's functional life?
- Do they address the needs of special user groups, for example, the elderly or the disabled?
- Do manufacturing decisions compromise product quality or functionality, or do market demands compromise efficient manufacturing?

As a Product Design Engineer you will be required to make these judgements and justify your claims for improved designs.

DPD20002 Product Design Engineering Studio **Project 2 Inside Out**

Assessment sheet

Student Names ………………………………………………………… ……………………………………………………………

(Contributes 65% to Design Studio mark)

Final Grade ………. /100

Deliverable	Unsatisfactory	Satisfactory	Good	Very good	Excellent	Appraisal
Stage A: Reverse Engineering Research						
A3 panel User Analysis	No research submitted No User Analysis Limited exploration on new designs	Moderate number of different images provided Images chosen do not represent-adequate User Analysis Presentation requires correction	Variety of different images provided Images chosen represent-User Analysis Some info on improvements Good layout Clean presentation	Many of interesting images provided Images chosen represent a very good User Analysis with digital annotations included Very Good info on improvements, Very good layout and clean presentation with some annotations	Excellent range of interesting images provided Images chosen show excellent understanding of User Analysis with digital annotations included Detailed info on safety, appliance features and improvements Professional presentation with descriptive annotations	
1XA3 panel BOM photos and Autopsy	No BOM, photos and Autopsy submitted No BOM spreadsheet shown	Limited BOM, photos and Autopsy submitted Parts poorly shown Limited BOM details in spreadsheet Background poor Presentation requires correction	Good BOM, photos and Autopsy submitted, Materials, weights and % included Parts shown but does not show assembly Limited BOM spreadsheet details i.e. materials or weights Presentation requires correction	Many of interesting images provided for Autopsy Parts shown are well detailed with enlarged views Very detailed BOM spreadsheet & details, materials, weights and % included All packaging and Instruction Book Inc. Very good layout and clean presentation	Excellent range of interesting images provided for Autopsy Parts shown are well detailed with enlarged views and scaled item included Fully detailed BOM spreadsheet & details, materials accurate, % and correct weights All packaging and Instruction Book included Prof presentation with constructive annotations	
1XA3 panel SOP Analysis	No research submitted Basic SOP Analysis Analysis has limited info	Limited SOP Analysis on key functions Analysis has limited info on final scenario Presentation requires correction	Good SOP Analysis on most functions Analysis has useful info for final scenario Good layout and Presentation	Very Good SOP Analysis on most functions Analysis has useful info for final scenario Very Good layout and Presentation	Very Good SOP Analysis on most functions Analysis has useful info for final scenario Professional Layout and Presentation	
1XA3 Hand Drawn Sectional view of existing product	Poor quality of illustration Sectional view not correct Poor presentation	Poor technique of illustrations All parts not fully shown Sectional view not accurate Poor presentation	Basic technique of illustrations, line work lack definition Most parts shown with correct orientation Some part names / numbers included Basic layout and presentation	Very Good illustration technique line work has good definition Parts are fully detailed and shown with correct orientation Part names / numbers included Very Good layout and presentation	Excellent illustration technique line work crisp and clear Parts are fully detailed and shown with correct orientation Part names / numbers included Professional presentation layout and presentation	/15
2XA3 panels on Target Market	Not submitted Insufficient detail on panel No name Limited exploration on Target Market	Moderate number of different images provided Images lack cohesion Basic Layout , Basic exploration on Target Market Present requires correction	Variety of different images provided Good layout Good exploration on Target Market and demographics Clean presentation, no references	Many of interesting images provided Strong visual layout with some digital annotations Very Good exploration on Target Market and demographics Clean presentation, some references	Many of interesting and novel images provided Strong visual layout with full digital annotations Excellent exploration on Target Market and demographics, with future scenarios Prof. presentation and extensive references	
(PDS) Product Design Specification						
A4 PDS Report	No submission No or PDS Report Poor quality presentation, no cover sheet, no details No photos of product Autopsy No or poor Bill of Materials No technology research included No or Poor Bibliography and Harvard referencing	Basic PDS Report structure Low quality presentation, poor binding, cover sheet, and details Basic Bill of Materials Poor photos of product Teardown, parts laid out in logical order, leader lines or numbers Instruction Book not included Poor technology research included Basic Demographic specified Poor Bibliography & Harvard referencing	Good presentation, binding, cover sheet, and details Good Detailed PDS Report listing most technical details, target market, price point, persona ect. Good Bill of Materials, weights and % included Good photos of product Autopsy, parts laid out in logical order, leader lines or numbers, Instruction Book included Some packaging and Instruction Book included Good technology research included Good details/images on Demographic specified, Good Biblio & Harvard refs	Very Good presentation, binding, cover sheet, layout throughout report and details A well Detailed Return Brief listing target market, price point persona etc. Very Good photos of product Autopsy, parts laid out in logical order, leader lines or numbers, that match the BoM, Instruction Book packaging included Thorough list for Bill of Materials, materials, weights and % accurate All packing and Instruction Book included Very good list of objectives / features / new material /technology selections Very Good technology and innovation research include, demographic specified Very Good Bibliography&Harvard refs.	Excellent presentation, binding, cover sheet, layout throughout report and details All Template points thoroughly covered listing; objectives, target market, price point, demographic persona, use patterns, etc. Excellent photos of product Teardown, parts laid out in logical order, leader lines or numbers, that match the BoM, Instruction Book packaging included Excellent list for Bill of Materials, weights and % included, Thorough technology and innovation research included Fully detailed list of objectives / features to improve design and detailed Eco Design Strategies Thorough details/images on Persona and Demographics chosen Very Detailed Bibliography & Harvard referencing	/15
Stage B: Concept Generation and Develop.						
Folio of annotated Concept sketches (10-12 pages min.)	Less than 8 pages produced Poor quality sketches Poor Hand sketches No annotations Less than 6 ideas exploring the scenario	10-12 pages produced Minimal annotations 6 ideas exploring the scenario Limited breadth of ideas Sketching technique could be refined, Sketches indicate min. exploration of the design	10-12 pages produced More than 6 ideas exploring the scenario with a Good breadth of innovation Sketches indicate good exploration of the design	More than 10-12 pages produced More than 6 ideas exploring the scenario with a Very Good breadth of innovation showing hands and use of product Sketches indicate very good exploration of the design and details Professionally presented	More than 10-12 Quality pages produced More than 6 ideas with Excellent breadth of innovation, showing hands and use of product Sketches indicate very good exploration of the design, sectional views and details Key concepts are rendered Professionally presented	
2XA3 Concept Illustration panels (1 per student)	Poor quality of ideas Poor quality of illustrations No hands or scale shown Poor presentation	Basic quality of ideas Poor technique of illustrations Some hands or scale shown Basic layout limited annotations Product may not fit chosen demographic	Moderate number of interesting designs Some novel illustrations provided Layout & Presentation OK, some digital annotations Some designs fit chosen demographic	2 novel designs that use interesting technology &materials Very Good illustration technique All details fully shown Quality Layout & Presentation, good digital annotations used, Designs matches chosen demographic	2 novel designs that use interesting technology &materials Excellent illustration technique All plastic details fully shown, hands and scale used Excellent Layout & Presentation, annotations Designs matches chosen demographic	/20
1 X A3 min. Orthogonal Drg and 1:1 Sectional View (CAD or Manual)	Poor quality detailing Poor technique Poor presentation	Basic information supplied Basic technique, no overall dimensions Poor sectional view that does not show all components	Good information supplied Good technique, overall dimensions accurate Good sectional view that shows all components	Very Good information supplied Very Good technique, overall dimensions accurate Accurate sectional view that details all components	Very Good information supplied Well documented engineering drawing, overall dimensions accurate Accurate sectional view that details all components	
Folio of Refinement sketches (5 pages min.)	Less than 5 pages produced Poor quality sketches Poor Hand sketches No annotations	5 pages produced Minimal annotations 6 ideas exploring the scenario Limited breadth of ideas Sketching technique could be refined and indicate minimal exploration of the design	5 pages produced exploring the assembly, manufacturing and tooling details, scenarios with a Good breadth of innovation Sketches indicate good exploration of the design	More than 5 pages produced exploring the assembly, manufacturing and tooling details, scenarios with a Very Good breadth of innovation Sketches indicate good exploration of the design	More than Quality 5 concept pages produced exploring the assembly, manufacturing and tooling details, scenarios with an Excellent breadth of innovation Sketches indicate good exploration of the design Professionally presented	
Final Illustration, Evaluation and Formstudy						
A3 Final Illustration panels (min. 3 CAD generated)	Poor quality of illustration Poor technique No hands or scale shown No annotations Poor presentation	Basic quality of idea Basic technique of illustration Some hands / scale shown Limited annotations describing features Product may not fit chosen demographic	Interesting and Novel ideas Good technique of illustration Good attempt at hands / scale Some annotations describing features Product matches chosen demographic Final design has some interesting features	Very interesting and Novel ideas shown Very Good technique of illustration Very Good attempt at hands / scale Digital Annotations thoroughly describes features with some user interaction shown Product matches chosen demographic Final design is innovative with some interesting features	Very interesting functions /materials in an Novel ideas shown Excellent technique of illustration Excellent attempt at hands / scale with user interaction shown Digital Annotations thoroughly describes features Product matches chosen demographic Final design is novel and innovative	/20
Photos of FormStudy, Blue Foam to test scale, proportion, functionality	No Photos of Form Study Form Study not to scale Form Study does not depict design intent	Poor quality photos of Form Study Poor quality details on Form Study Some of the Design intent is depicted	Good quality photos of Form Study Good quality Form Study depicts design intent	Very Good quality photos of Form Study Very Good Formstudy depicts design intent very clearly Very Good finish and accuracy of details	Excellent quality photos of Form Study Excellent Form Study depicts design intently very clearly Excellent Finish and accurate details including user interface / buttons	
Technical Documentation						
Eng Drawings toAS1000, sectional views materials,title,block, tolerance	Poor quality of Drawings Poor technique No sectional views No Exploded view Poor presentation	Some Drawings to AS1000 Basic sectional view Basic Exploded view Poor technique Title block not complete	All Drawings to AS1000 Good sectional view with overall dimensions Good Exploded view Title block complete	All Drawings to AS1000 Very Good sectional view with overall dimensions Very Good Exploded view Title block complete. Toler. accurate	All Drawings to AS1000 Very Detailed sectional view with overall dimensions Excellent Exploded view Title block complete, tolerances and materials accurate	/20
Final Presentation						
Oral presentation	No Oral presentation Poorly organized oral that Does not cover the reqd.info	Oral presentation is limited and not well organized; some of the required content is covered.	Oral presentation is well organized and covers all of the required content	Oral presentation is very well organized and covers all of the required content in some depth	Oral presentation is very well organized and very clearly communicates all of the required content in depth	
Visual Presentation	No visual presentation Poor Layout of image and text Not all the required images are included	Visual presentation is satisfactory Some images too small Viewpoints for images could be more communicative Most of the design intent is communicated	Visual presentation is Good Most of the images are clear and communicate design intent Viewpoints for images could be more communicative Text is neatly laid out	Visual presentation is Very Good All of the images are clear and communicate design intent Images clearly communicate context and use Text is neatly laid out	Excellent representation of form, volume and materials, scale, use and context. All of the images are clear and clearly communicate design intent Text is neatly laid out	/10
	0 – 50 Fail	**50 – 60 Pass**	**60 – 70 Credit**	**70 – 80 Distinction**	**80 – 100 High Distinction**	

Note that all marks are provisional until after moderation at the end of semester.

DPD20002 Inside Out Rubric (3).docx

Appendix XXI

DPD30001 Advanced Product Design Unit Outline 2015

Project Background

This project is designed to explore a relatively new water heating technology, and to utilize this technology to develop new energy efficient products. Students will be working with a company, Microheat Technologies Participating in a Design competition produce the most innovative solution using the Microheat technology and a 'Whole Systems' approach.

The primary objective of the project is to find new applications for the Microheat Water Heating Technology within an allocated scenario and to prove that the application is viable by developing a manufacturable Design solution, undertaking a Environmental analysis and benchmarking against exiting competing products. This is a real project for a real client, which will be run as a competition that will be judged based on the final student Pitch to staff from Microheat at the end of the project. Microheat will assess the work against the following criteria to rank the student outcomes (this ranking has no bearing on your Academic result and is independently undertaken by Microheat staff):

- Innovation Design – What's new and innovative in the proposal?
- Technical Design – Quality of resolution of Engineering and Manufacturing proposal
- Aesthetics – Are these appropriate for the target market and well resolved and communicated?
- Presentation Pitch – The Pitch is convincing and supported by research
- Potential Market/Addressable Market – The Target Market is appropriate and clearly identified.

The client – Microheat Technologies Pty Ltd

MicroHeat Technologies Pty Ltd is a successful Australian private business focusing on the research and development of highly advanced systems in the field of rapid fluid heating technology for both domestic and industrial applications. The technology is proprietary (patent protected in over 52 countries). In relation to domestic water heating applications, the technology promotes significant reductions in energy and water usage, thereby reducing greenhouse gas emissions. The MicroHeat technology methodologies create a paradigm shift in the way industry and society thinks about heating water (disruptive technology). The Continuous Flow Electrical Water Heater (CFEWH) relies on the conductivity of the water. The water is energized using inert electrodes positioned in the water stream. It incorporates a microprocessor based control / feedback loop that delivers absolute outlet temperature control at any flow rate or fluid input temperature accurate to (+/- 1.0 deg C). The system calculates the exact energy required to heat the water to the set temperature at the existing flow rate, which can be as low as 1.5ltr/min. This results in key functional and commercial differentiation aspects when compared to current "instantaneous" hot-water appliances. The global market potential is enormous, a fact that has been recognised by Government through funding grants. MicroHeat enjoys strategic alliances with world-class suppliers, manufacturers, toolmakers, OEM's and multinational consortiums.

Background - the market

The water heating market (domestic and commercial) is one which has come under increasing scrutiny on the local scene, with government and regulatory bodies tightening the constraints on water and energy efficiency, generally with the best intentions on mind, but maybe not the most effective 'Whole Systems' delivery of solutions. Water heaters are highly regulated, and subject to limitations through the Building Code of Australia (BCA) in conjunction with standard tests through relevant Australian Standards:

AS1056 - Storage water heaters - General requirements
AS3500 - Plumbing and drainage Set
AS4234 - Heated water systems - Calculation of energy consumption
AS4445 - Solar heating - Domestic water heating systems - Performance rating procedure (indoor test)
AS4552 - Gas fired water heaters for hot water supply and/or central heating
AS4692.1 - Electric water heaters - Energy consumption, performance and general requirements
AS4692.2 - Electric water heaters - Minimum Energy Performance Standard requirements / energy labelling
AS/NZS 60335.1 & AS/NZS 60225.2.35 – Bare Element Water Heaters
AS/NZS3000 – Australian Wiring Rules

One major movement by government has been to phase out greenhouse intensive water heaters with the new BCA (Building Code of Australia). Currently, the recommendations (Wilkenfeld and Associates, 2009) put forward to the Australian Government to amend the current BCA states the following regarding efficiency and greenhouse factors:

Stage 1- Scoping and Ideation *20% project marks*

Part A;
Review the current technologies available and competing products in your allocated scenario, look at Energy and Water usage specifically as well as price point. Strengths and Weaknesses of products in the current scenario should be identified. Brainstorm potential products that could use the MICROHEAT technologies as identified by your research, with a view to looking for energy efficiency, sustainable energy sources and new product ideas
Part B; ideas and ways to solve the problem
Generate a series of product ideas (minimum 10 preliminary ideas in sketch form and bring to class for informal review and pin up as a series of A3 pages of annotated Sketches.
Select one idea to develop further in consultation with staff and peers.

Part C; Preliminary Scoping Presentation Preliminary Scoping Presentation
3-4 x pdf slides accompanied by an oral presentation

- 1x PDF slide slide explaining current technologies and competing products in the given scenario
- Describe the Return Brief (What is your design proposal and what does it do?)
- 1 – 2 slides showing preliminary ideas in sketch form
- 1 – 2 slides showing preferred 3 directions that are more refined ideas (your best ideas, further refined with some annotations). As a guide the 3 ideas that are developed further should be for 3 different applications of the Microheat Technology within your allocated scenario.

Part D : Concept Generation - Mid Semester Presentation
Further develop one concept direction as determined in the Part A and identified from Staff feedback.
Explore overall aesthetics and usability of the product in sketch form and bring to class for informal review and feedback
Investigate Human interaction with the product via the production of a 1:1 scale mock-up and or drawing
Write a Detailed Product Design Speciation as per the template provided.

- 5 minute Oral presentation
- 2x PDF slides presentation PDF slides explaining the final concept proposal and how it works
- 1:1 scale Foam Mock-up and or Full size drawing to test scale, proportion and Human factors

Stage 2; Detail Design *25% project marks*

Detail Design (progressive review weeks 7-11)
Detail the product for manufacture, with attention to part design for mass production techniques, logical assembly order and orientation of internal components, layout and determination of the size and geometry of the mircroheat componentry based on energy and water flow calculations. Consideration of Design for Environment Strategies in minimizing parts, access and upgrade, specification of Eco materials where practical, specification of durable materials, energy efficiency etc

Deliverables; (these will be assessed progressively, refer to the Major Project Schedule for due dates)

Part A; 1;1 component layout. This may be CAD generated, or neatly hand drawn, it must be printed so that staff and peers can mark it up. It may be a section or series of section view.
Part B; Exploded View pin up in class for peer review. Hand drawn exploded view, in perspective with parts labelled. These drawings should accurately indicate part geometry, adherence to manufacturing constraints (such as draft on moulded parts for example) and the logic and order of assembly.
Part C; Work in progress presentations of Edrawings in class for lecturer and Peer review. Please download edrawing software, this software interfaces with solidworks allowing a smaller more portable file size that can be viewed on either a Mac or PC computer. Your model should be approx. 80% complete.
Part D; Weekly review of Detail Design Sketches, Cad Plots and on screen reviews, meeting milestones

Stage 3: Verification and Engineering Documentation Deliverables *40% project marks*

Part A; Documentation 3d CAD model - Solidworks
Detail design of all parts in 3d CAD, Standard components may be modelled as simplified parts showing overall shape and any clearance or mounting points. These files should be exported as both IGES and EDRAWINGS and uploaded to Blackboard if file sizes permit or use Dropbox file transfer.

Part B; Engineering Drawings to As1100 Drawing Standard
1. Exploded view explaining all parts, showing assembly and component layout (suggest at a2 or larger page size)
2. A minimum of 2 or more Section views through the product indicating typical details and component layout

3. An Assembly drawing accompanied by a BOM (showing the specification of materials based on environmental properties and appropriate for Mass Production processes)

Part C; Environmental Aspects of the Design Proposal
Submit to Blackboard as A4 multipage report PDF document containing the following:

***Task 1* Energy Load and Water consumption for your Design**

a. Work out a suitable volume flow rate for your scenario. For static appliances, work out a suitable volume to be heated. Determine the power required to heat the volume flow rate or volume of water.
b. Determine the energy load and water used per annum for your product based on average water use in selected scenario.

Task 2 Energy Load and Water consumption for competitor's product
Identify suitable competitor product, appliance or system. Find out the energy rating, storage in situ. and pipes, and thermal performance of that competitor (ie insulation, energy required to heat stored water, etc).

a. Determine where competitor losses occur (ie storage tank losses, pump energy, pipe heat losses, total water slug loss per use), and estimate how much they are per annum.
b. Determine competitor energy load and water used per annum based on average water use in selected scenario, including energy/water losses.

Task 3 Energy Load and Water consumption comparison

a. Compare the water and energy consumption of your product compared to you competitor product, enter these figures into the use phase section of Greenfly for both products
b. Conclude findings with a summary of results, including justification of your design compared to your competitor, based on energy, water and greenhouse gases.

Task 4 Environmental Analysis using GREENFLY
Undertake an Environmental Analysis for the parts of the Product that you have designed (ie not the infrastructure where the Mircroheat is installed) using GREENFLY to highlight the sustainable aspects of your product proposal and document in PDF

Stage 4: Presentation Pitch Deliverables — *15% project marks*

Part A; Final Oral presentation and PDF presentation – 10 minutes with 5 minutes for questions

Suggested content –

- Introduction scenario (what problem are you solving) the technology utilized and the objectives of the product
- A series of strong concept visuals showing all the features of the product
- What inspired this design?
- Exploded view showing the component layout and assembly of the unit, how does heating system work? (this may be a series of still images or an animation)
- A series of detail views that explain the detail design aspects of the product, including any chassis, fixings, should include some section views, explain materials choice etc
- Outcomes of Environmental Analysis

Conclusion as how you satisfied the brief, including why your proposal is a good application of Microheat's technology.

- ***Part***

Part B; Final mock-up
Final Form study using Blue Foam at 1;1 Scale or other scale as approved by your lecturer ;**external surfaces only required**. You may print rendered buttons screens etc to indicate fine features at 1:1 scale (or other scale as agreed with your lecturer).

Part C: Reflective Text and team review.
Personal Feedback on the project

- 500 word individual reflection on your experience of undertaking the project (one per team member).
- The Team Review Form can be submitted confidentially to Kate Bissett Johnson via email, kbissettjohnson@swin.edu.au, each member of the team must submit this independently.

It is also suggested students should adhere to a naming convention for digital files, Student or team name, project name, file description file extension
(eg john_frank_vendingmacine_sideview.jpg)

Appendix XXII

VAK Learning Style Test

VAK Learning Styles Explanation

The VAK learning styles model suggests that most people can be divided into one of three preferred styles of learning. These three styles are as follows, (and there is no right or wrong learning style):

- Someone with a **Visual** learning style has a preference for seen or observed things, including pictures, diagrams, demonstrations, displays, handouts, films, flip-chart, etc. These people will use phrases such as ‘show me’, ‘let’s have a look at that’ and will be best able to perform a new task after reading the instructions or watching someone else do it first. These are the people who will work from lists and written directions and instructions.

- Someone with an **Auditory** learning style has a preference for the transfer of information through listening: to the spoken word, of self or others, of sounds and noises. These people will use phrases such as ‘tell me’, ‘let’s talk it over’ and will be best able to perform a new task after listening to instructions from an expert. These are the people who are happy being given spoken instructions over the telephone, and can remember all the words to songs that they hear!

- Someone with a **Kinaesthetic** learning style has a preference for physical experience - touching, feeling, holding, doing, practical hands-on experiences. These people will use phrases such as ‘let me try’, ‘how do you feel?’ and will be best able to perform a new task by going ahead and trying it out, learning as they go. These are the people who like to experiment, hands-on, and never look at the instructions first!

People commonly have a main preferred learning style, but this will be part of a blend of all three. Some people have a very strong preference; other people have a more even mixture of two or less commonly, three styles.

When you know your preferred learning style(s) you understand the type of learning that best suits you. This enables you to choose the types of learning that work best for you.

There is no right or wrong learning style. The point is that there are types of learning that are right for your own preferred learning style.

Please note that this is not a scientifically validated testing instrument – it is a free assessment tool designed to give a broad indication of preferred learning style(s).

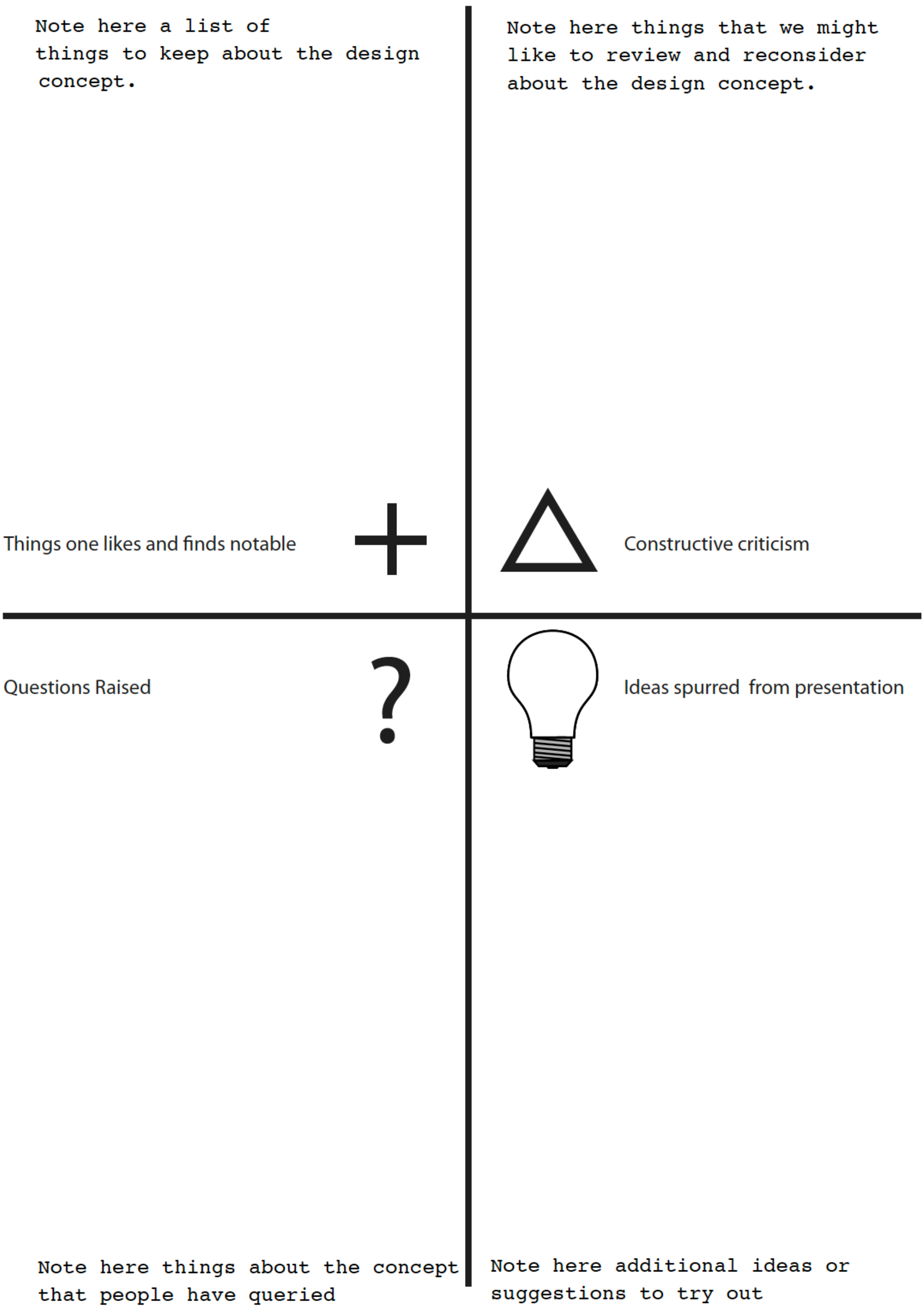
More information about learning styles, personality, and personal development is at www.businessballs.com.

With acknowledgements to Victoria Chislett for developing this assessment.

Appendix XXIII

Feedback capture grid for peer review

FeedBack Capture Grid



Appendix XXIV

Suggestions for tutors to do in ME tutorials

- Make sure the teams are formed early in the semester
- Expect to see the progress of each team and to discuss their design
- Go prior to the class to arrange the furniture appropriate for a group discussion
- Clearly explain the students that creativity is an assessment criterion and you expect them to be creative
- Arrange group discussions and provide an atmosphere for peer evaluation
- Encourage students to use the tutorial hours to apply creativity tools and to develop their designs
- Remind students what you are expecting the following week and check their progress each week
- Encourage all students to sketch and draw, to use a folio, and provide them A4 blank paper for drawing
- Remind students to keep their sketches and drawings for further use
- Avoid discouraging language
- Rather than being an expertise of authority, try to be a coach or facilitator
- Conduct brainstorming sessions during tutorial hours
- Ask students what they think about creativity, the definition of creativity, and what they understand from creativity
- Go through the unit outline with students and tell them the importance of the design process
- Ask students about the benefits of team-working and keeping a folio, and explain the reasons why we are doing it this way

Appendix XXV

A list of questions for brainstorming session

Q1. If you turn your chair upside down, how can you use it for what purpose?

Q2. How can we re-use a 0.5 litre plastic water bottle?

Q3. What if the whole computer networking system fails (shuts down) for a week in the whole world, what would happen?

Q5. One of the early symptoms of Parkinson disease is the shaking of hands. These patients are not able to eat their food by themselves. How can you improve their eating practice?

Q6. How can you squeeze oranges to make orange juice in a space ship where there is no gravity?

Q7. How can you keep children's room tidy without tidying it?

Q8. Holden use single stage airbags for local market and dual stage airbags for cars they export to the US. Dual stage airbags are required for unbelted occupants - seatbelts are not legislated in some states. How can you ensure the right airbag has been fitted to the right car?

Appendix XXVI

How to conduct brainstorming sessions?

The aim of the brainstorming session is to generate many ideas and possibilities to a given problem. At this stage, students should let their minds free. Criticism will come later. The more the students practice, the better they learn about using these kinds of creativity tools. First attempt can include the whole class discussing a basic subject that might not even be related with the unit. During this first attempt, you, as the tutor, will be the facilitator. You should guide the conversation, take notes during idea generation process and produce a post-session report.

You should first read the rules of the brainstorming loudly, and tell the students clearly what you expect from this process. Introduce the subject and give them the turn to talk. As they generate ideas, you write them one by one. If the idea generation process turns into a conversation, it is your duty to guide the students to focus back on the subject again. If they are not listening to each other and trying to talk simultaneously, you kindly pause the session and tell them to raise their hands before talking and you approve who will talk when. When you feel that they are out of ideas after a while, you can finalise the session. In the end, you can quickly organise and summarise what ideas have been created and read them to class. This whole process should not exceed more than 10-15 minutes.

In the second attempt, make sure the team members of 3 or 4 come together and sit in a position by facing each other. Try to use the classroom area efficiently. If needed, organise the desks and chairs in a position allowing each team has their discussion area and the team members can see each other easily. This time, they can brainstorm about the design problem. Each team needs to have a facilitator. Let them decide their facilitators, who will have the responsibility to guide their teams, and to write down the ideas. In the meantime, they are also welcomed to talk and to generate ideas. Your position will be checking each team one by one during the brainstorming session if they are on the right track and make sure they are not arguing offensively or very loudly. It is encouraged that the facilitators write all the ideas popped out, and use an A3 size blank paper. The tutors can provide A3 size papers.

The third attempt can be given as homework. They can continue brainstorming about the design project. Encourage the students to organize their brainstorming ideas by doing a mind map.

Tutors should not forget that; this tool aims to help generating as many ideas as possible. The more ideas are generated; it is more likely that students can find a better solution. However, having lots of ideas does not necessarily bring quality solutions or innovative ideas. So, when facilitating the brainstorming session, tutors should be aware of the fact that the students need to build on these ideas later on. After the session, students need to sit together and organize their ideas generated during brainstorming by using mind map, or affinity chart techniques. Then it comes to criticise the ideas.

Appendix XXVII

Brainstorming

Faculty of Engineering and Industrial Sciences

Higher Education Division

SWINBURNE UNIVERSITY OF TECHNOLOGY

BRAINSTORMING

The aim of the brainstorming session is to generate many ideas and possibilities to a given problem. At this stage, let your minds free. Criticism will come later. The more you practice, the better you learn about using these kinds of creativity tools. One of you needs to be the facilitator; guide the conversation, take notes, write down the ideas during idea generation process and produce a post-session report. Facilitators are also welcome to talk and to generate ideas.

Osborn, as the creator of brainstorming, set basic rules about the tool (Zhou, 2012c; Lumsdaine & Lumsdaine, 1995b). Please read them.

1. Generate as many solutions as possible.

Quantity counts.
No need to give long explanations along with your ideas, be simple.
Ideas do not have to be completely new.
Listen to other people's ideas. You can expand or build on them.
You can improve the ideas of your friends.
The more ideas you generate individually or collectively, the better the chance that you come up with an innovative solution.

2. Wild ideas are welcome.

The more odd, weird, impossible, or crazy ideas are generated, the better. The only limit here is to avoid words and ideas that could be hurtful or offensive to your team members.
Always keep the team spirit alive and be respectful to others.
Don't let the stress inhibit creative thinking.

3. Criticism is ruled out.

Welcome freewheeling.
Critical judgement or evaluation is deferred until later.
Do not put down ideas or the people who express them.
Humour, favourable comments, laughter are all OK.
There is no such thing as a right or wrong answer in brainstorming.

Negative comments that reduce Brainstorming to Braindrizzling
(Fogler & LeBlanc, 1995):

That won't work.
That's too radical.
It's not our job.
We don't have enough time.

That’s too much hassle.
It’s against our policy.
We haven’t done it that way before.
That’s too expensive.
That’s not practical.
We can’t solve this problem.

This tool aims to help generating as many ideas as possible. The more ideas are generated; it is more likely that you can find a better solution. However, having lots of ideas does not necessarily bring quality solutions or innovative ideas. So, when facilitating the brainstorming session, you should be aware of the fact that you need to build on these ideas later on.
After the session, sit together and organize your ideas generated during brainstorming by using mind map, or affinity chart techniques. Then it comes criticising the ideas.

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Appendix XXVIII

6-3-5 Method

Faculty of Engineering and Industrial Sciences

Higher Education Division

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6-3-5 METHOD

6-3-5 Method is "a modified brainstorming technique" (White et al., 2012). In this method, number of participants and concepts are limited with numbers and the duration is limited with minutes. 6 participants are expected to develop 3 concepts per person in 5 minutes of silent brainstorming (quick sketching and taking notes). Then participants pass their concepts clockwise to their nearest neighbors, and they review each concept to add any modifications or enhancements on the original concepts. Every five minutes the rotation renews, until the concepts are returned to the original authors. All the activities are done individually and without talking (Genco et al., 2012; Oman & Tumer, 2010).

You can modify this method to 4-3-5 if the teams are made of 4 people (4 people, creating 3 ideas each, in 5 minutes). There will be 4x3=12 ideas for each team.

- Each team will focus on their design problems.
- Set the time for 5 minutes. Each individual in the team needs to come up with 3 ideas in 5 minutes. Each idea will be drawn on a separate sheet. There will be only drawing and short notes, no talking.
- After the session is completed everyone pass their ideas to the person sitting next.
- 5 minutes of reviewing each concept to add any modifications or enhancements.
- Pass the sheets again and set 5 more minutes for reviewing.
- Continue until the concepts are returned to the original authors.
- Lastly, it is time to review all ideas and to discuss for developing the ones which have potential.

White, C., Wood, K., & Jensen, D. (2012). From Brainstorming to C-Sketch to Principles of Historical Innovators: Ideation Techniques to Enhance Student Creativity. *Journal of STEM Education, 13*(5), 12-25.

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Appendix XXIX

SCAMPER

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SCAMPER is an acronym for:

Substitute
Combine
Adapt
Modify
Put to another use
Eliminate
Rearrange/Reverse

Spend 5 minutes for each team of questions.

Substitute
alternate, exchange, fill in for, rename, replace, reposition, surrogate, swap, switch

What materials or resources can you substitute or swap to improve the product?
What other product or process could you use?
What rules could you substitute?
Can you use this product somewhere else, or as a substitute for something else?
Can I change its parts / shape / color / sound?

Combine
amalgamate, become one, blend, bring together, join, link, merge, mingle, unite

What ideas or parts can be combined?
What would happen if you combine this product with another?
What if you combine purposes or objectives?
What could you combine to maximize the uses of this product?
How could you combine talent and resources to create a new approach to this product?

Adapt
acclimatize, adjust, amend, become accustomed, fit, get used to, match, settle in

What else is like your product?
Who or what could you emulate to adapt this product?
What other context could you put your product into?
What other products or ideas could you use for inspiration?
What could I copy, borrow or steal?

Modify
enlarge, expand, extend, grow, heighten, increase, lengthen, make seem more important, multiply, overemphasize, raise, strengthen

How could you change the shape, look, or feel of your product?
What could you add to modify this product?
What could you emphasize or highlight to create more value?
What element of this product could you strengthen to create something new?
What can be magnified?

Put to Another Use
apply, contextualize, manipulate, reposition

What else can it be used for?
Can you use this product somewhere else, perhaps in another industry?
Are there new ways to use it in its current shape or form?
Who else could use this product?
How would this product behave differently in another setting?
Could you recycle the waste from this product to make something new?

Eliminate
abolish, destroy, exclude, excrete, get rid of, limit, lower, reduce, reject, remove, restraint, restrict, shorten, simplify, throw out, underemphasize

How could you streamline or simplify this product?
What features, parts, or rules could you eliminate?
What parts can be removed without altering its function?
What would happen if you took away part of this product?
Can I compact or make it smaller?
What can be minified?

Reverse / Re-arrange
go backward, invert, move backward, readjust, rearrange, relocate, reorder, reorganize, reposition, reschedule, retreat, switch

What if I try doing the exact opposite of what I originally intended?
What would happen if you reversed this process or sequenced things differently?
How could you reorganize this product?
What other arrangement might be better?
Should I turn it around? Up instead of down? Down instead of up?
What if I consider it backwards?

Questions are retrieved from these websites:

Mind Tools (2015). *SCAMPER Improving products and services*. Retrieved February 05, 2015, from https://www.mindtools.com/pages/article/newCT_02.htm

Litemind (2015). *Creative Problem solving with SCAMPER*. Retrieved February 05, 2015, from https://litemind.com/scamper

Appendix XXX PMI Method

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PMI Method

PMI technique is suggested by Edward de Bono to improve your thinking. It is easy to use and helps your reviewing process. You will simply follow these steps:

1. Write down all the **Plus (positive/good)** points of the design
2. Write down all the **Minus (negative/bad)** points of the design
3. Write down all the **Interesting (creative/innovative)** points of the design

You can apply this to your own designs and then consider all before making any further decisions.

PLUS POINTS

MINUS POINTS

INTERESTING POINTS