Investigating the Suitability of Computerised Creativity Training Activities for Teaching Creativity and Problem-Solving Skills in Engineering Education

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Declarations

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

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List of Publications

This section outlines the related works that Andrew has contributed to during this course of study.

The following publications and in-progress works have resulted from this work:

Refereed Journal Articles

- **Valentine, A.,** Belski, I., & Hamilton, M. Investigating the presence of a mode-effect on engineering students’ self-efficacy during idea generation. *(Under Review)*
- **Valentine, A.,** Belski, I., & Hamilton, M. Creativity in electrical engineering degree programs: where is the content? *(Under Revision)*

Conference Papers (Peer Reviewed)

List of Publications

Engineering Education (pp. 1109-1116). Manly, Australia: School of Engineering, Macquarie University


Conference Papers (Peer Reviewed) (Non-Thesis Related)

Andrew has contributed to the following publications during this period of study which are not related to the thesis:


Conference Presentations

Andrew has presented at the following conferences during this course of study:


Presentation of Related Work in Other Formats

1. Oral Presentation, Lappeenranta University of Technology, Finland, September 2016.
2. Oral Presentation, School of Electrical and Computer Engineering 3 Minute Thesis Competition RMIT University, Australia, July 2016. ➢ Best Student Presentation Award.
## Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>CBG</td>
<td>Computer Based Group</td>
</tr>
<tr>
<td>CBT</td>
<td>Computer Based Test</td>
</tr>
<tr>
<td>CG</td>
<td>Control Group</td>
</tr>
<tr>
<td>CSS</td>
<td>Creativity Support System</td>
</tr>
<tr>
<td>DSS</td>
<td>Decision Support System</td>
</tr>
<tr>
<td>EBS</td>
<td>Electronic Brainstorming</td>
</tr>
<tr>
<td>GDSS</td>
<td>Group Decision Support System</td>
</tr>
<tr>
<td>ICSS</td>
<td>Individual Creativity Support System</td>
</tr>
<tr>
<td>KTCPI</td>
<td>Khatena-Torrence Creative Perception Inventory</td>
</tr>
<tr>
<td>MIS</td>
<td>Management Information Systems</td>
</tr>
<tr>
<td>NBS</td>
<td>Nominal Brainstorming</td>
</tr>
<tr>
<td>OECD</td>
<td>Organisation for Economic Co-operation Development</td>
</tr>
<tr>
<td>PBT</td>
<td>Paper Based Test</td>
</tr>
<tr>
<td>PISA</td>
<td>Programme for International Student Assessment</td>
</tr>
<tr>
<td>PPG</td>
<td>Pen-and-Paper Group</td>
</tr>
<tr>
<td>STEM</td>
<td>Science, Technology, Engineering and Mathematics</td>
</tr>
<tr>
<td>TRIZ</td>
<td>Teoriya Resheniya Izobretatelskikh Zadach (Russian)</td>
</tr>
<tr>
<td></td>
<td>Theory of Inventive Problem Solving (English)</td>
</tr>
<tr>
<td>TTCT</td>
<td>Torrence Test of Creative Thinking</td>
</tr>
<tr>
<td>VBS</td>
<td>Verbal Brainstorming</td>
</tr>
</tbody>
</table>
Abstract

Creativity and problem-solving are key skills which engineering graduates are expected to possess. While some studies report completing a four-year engineering program has a positive influence on creativity and problem-solving skills, others highlight that creativity skills may actually decrease over this time. Several studies report that creativity is given insufficient space within engineering curriculum, highlighting a contributing factor to this issue.

Creativity is a complex process involving numerous phases. The scope of this thesis is focused on the development of idea generation skills, and overcoming the issue of fixation. This thesis will primarily focus on the development of creativity skills through training in the use of creativity heuristics. Due to scope limitations, the practicality or viability of ideas will not be evaluated.

The purpose of this study was to:

- Quantify the coverage of creativity material within engineering curricula in Australia and New Zealand.
- Establish whether creativity training learning activities traditionally completed using pen-and-paper in a classroom environment can be successfully migrated to an online environment, without the influence of negative mode-effects on student learning outcomes.
- Establish whether online creativity training activities are a viable way for teaching engineering students creativity and problem-solving skills.

The following research objectives were investigated:

- Establish the extent that creativity-related topics are explicitly taught within engineering curricula in Australia and New Zealand, specifically including creativity heuristics training.
- Establish whether there is a mode-effect in the context of creativity heuristics training, based upon ideation performance and self-efficacy.
- Establish whether there is any measurable long-term benefit for students to spend time engaged in tasks that expose them to the use of creativity heuristics, and whether there is a long-term mode-effect on ideation performance.
- Establish from an educator’s point of view whether creativity heuristics training is viable, and when and how it should be introduced to engineering curricula.
- Establish whether students prefer to complete creativity heuristics training using one mode or the other (computer or pen-and-paper).

This study utilised a mixed methods approach using both quantitative and qualitative methods in different stages of the study:

- The first phase was a mixed methods research design. 1109 publicly accessible course outlines from forty-nine Australian and New Zealand electrical engineering programs hosted by thirty-two different institutions, were analysed to collect data and carry out evaluations.
The second phase included three quasi-experiments, using a primarily quantitative research design. The first experiment involved seventy first year students, one hundred and fifty-three third year students and thirty-eight postgraduate students. The second experiment involved ninety third year students. The third experiment involved forty-eight first year students.

The key findings of the study are:

- Quantification of the coverage of creativity-related material in engineering curricula on a national level as opposed to being limited to one or two tertiary institutions.
- There is no observable mode-effect in the context of creativity training where students learn to apply creativity heuristics, based upon either ideation performance or self-efficacy.
- Engaging engineering students in a standalone idea generation activity of less than an hour duration has measurable performance benefits, and there was no observable difference in longitudinal ideation performance based on mode used in the creativity training.
- Students show positive interest towards standalone learning activities designed to enhance their creativity and idea generation skills. As an overall cohort, students show slight preference for completing such activities using computer over pen-and-paper.
- First year students may be more willing or able to make use of creativity heuristics training. Students in higher year levels may be more resistant to learning such topics.

The key findings have implications for practice. When designing engineering curricula, the following factors should be taken into account regarding the development of creativity and problem-solving skills:

- Engineers Australia and Engineering New Zealand may adapt their criteria for assessing whether engineering programs foster creativity skills or not. Engineering programs should require students to explicitly learn about creative theory and creativity techniques, as opposed to implicitly only through the completion of engineering design projects.
- It is recommended courses focused on developing creativity and problem-solving skills are introduced to first year of study. Additionally, creativity material should be increased throughout the engineering program.
- Developing online creativity training activities and making them widely available may be one way which the creativity and problem-solving skills of engineering students may be effectively enhanced throughout an engineering degree. Especially where an institution otherwise has a lack of creativity-related material throughout their engineering curricula.
- Making creativity training available in students’ first year of study is ideal as students may be more willing to engage with the activity, and it provides more time throughout their degree when they can practice and make use of the training.
The research findings of the study contribute to the existing literature in the following ways:

- Much more comprehensive understanding of the extent of coverage of creativity-related material within Australian and New Zealand engineering education.
- Better understanding of the influence that creativity heuristics training has on students’ longitudinal idea generation performance.
- Substantial addition to the available literature in regards to mode-effect in the context of creativity training activities, both in terms of initial and longitudinal effects.
- Contribution to the understanding of mode-preference within different contexts. Within creativity heuristics training, students show preference for using computers.
- Identification that students show positive attitudes specifically towards creativity heuristics training activities, as opposed to creativity in general or courses focused on creativity.

Results of this study provide useful information for educators relevant to teaching creativity and problem-solving skills within engineering education.

Findings in this thesis can lead to the increased adoption of creativity material within engineering curricula, and the development of online applications which can engage engineering students in building their creativity and problem-solving skills.

Future work may conduct longitudinal research to establish whether engaging students in creativity heuristics training regularly throughout their program of study, can lead to observable benefits to their creativity skills upon graduation. Future research may expand the types of creativity training considered, and broaden the focus to include aspects of creativity training other than heuristics.
Chapter 1: Introduction and Thesis Structure

This section will present a concise summary of the motivations and objectives for this project, contributions of the thesis to the literature, and an overview of how the objectives are met the thesis structure and relevant publications.

The motivations and objectives are derived from the literature reviews covered throughout Chapters 2 and 3.

1.1 Motivations and Objectives

1. Establish the extent to which creativity and innovation related topics are explicitly taught within engineering curricula in Australia and New Zealand, specifically including ideation-based creativity heuristics training.

2. Establish whether there is a mode-effect in the context of ideation-based creativity heuristics training.
   a. Mode-effect on ideation performance.
   b. Mode-effect on self-efficacy.

3. Establish whether there is any measurable long-term benefit for students to spend time engaged in standalone tasks that expose them to the use of creativity heuristics, and whether there is a long-term mode-effect on ideation performance.

4. Establish from an educator’s point of view whether ideation-based creativity heuristics training is viable, and when and how it should be introduced to engineering curricula.
   a. Whether students see benefit and are interested in ideation-based creativity heuristics training.
   b. What year level of study should students learn such material.

5. Establish whether students prefer to complete ideation-based creativity heuristics training using one mode or the other, specifically pen-and-paper or computer.

1.2 Thesis Contributions

1. First study in the literature to conduct a review and quantify the coverage of creativity related material in engineering curricula on a national level (Australia and New Zealand), opposed to being limited to the study of one or two tertiary institutions.

2. First study in the literature to demonstrate that there is no observable mode-effect in the context of creativity training where students learn to apply creativity heuristics, based upon either ideation performance or self-efficacy.

3. First study in the literature to demonstrate that engaging engineering students in a standalone idea generation activity of less than an hour duration has measurable performance benefits, and that there is no observable mode-effect on ideation performance based upon the mode used in the initial creativity training.

4. First study in the literature to demonstrate that students show positive interest towards short standalone learning activities designed to enhance their creativity and idea generation skills.

5. First study in the literature to demonstrate that students show a slight preference for completing creativity training activities using a computer-based interface over pen-
Chapter 1: Introduction and Thesis Structure

and-paper. In addition, this is the first study in the literature to directly compare and evaluate the usage rates of learning resources which were made available in two digital formats, where students had the option of which (or both) digital format to use.

1.3 Thesis Structure

This section will provide an overview of the structure of the thesis, and the contents of each Chapter.

Chapter 2 will detail a literature review of creativity within the context of engineering education. This will include discussion of what is creativity, why creativity is important, how well engineering curricula enhances the creativity or students and potential shortcomings, creativity in the context of engineering problem solving, self-efficacy, stakeholders’ interest in creativity, and how creativity can be enhanced in higher education settings.

Chapter 3 will detail a literature review of digital technologies, focusing on the mode-effect. This will include discussion of what the mode-effect is, what may cause the mode-effect, tasks where the mode-effect is observed, what may be done to overcome the mode-effect, and how mode preference may or may not relate to task performance. The Chapter will also include detailed analysis of how computers can assist people to be creative, and the types of software which assist people to be creative and how they work.

Chapter 4 will detail a review that was undertaken to establish to what extent creativity-related material, and specifically creativity heuristics and techniques, are explicitly taught within electrical engineering curricula within Australia and New Zealand.

Chapter 5 will detail an experiment designed to answer objectives 2a and 4b, as well as some other factors in creativity heuristics training. This Chapter will focus on whether there is an observable mode-effect in the context of creativity heuristics training. In addition, the experiment will investigate whether other factors including template design and student enrolment type (local or international) are important factors which educators must consider when designing creativity heuristics training activities.

Chapter 6 will detail an experiment designed to answer objective 3. This Chapter will focus on identifying whether involvement in the experiment from Chapter 4 lead to measureable long-term ideation performance benefits, and whether the mode used in creativity heuristic training influenced long-term ideation performance. In other words, whether there is an observable long-term mode-effect on ideation performance.

Chapter 7 will provide details of an experiment designed to answer objectives 2b, 4a, and 5a. This will include whether there is an observable mode-effect on self-efficacy during creativity heuristics training, whether students show interest in creativity training activities, and whether students prefer to complete creativity training activities using pen-and-paper or computer.

Chapter 8 will present a model of factors which were found to influence (or not) ideation performance and self-efficacy during creativity training activities. The models are based upon the experiment findings and are applicable for educators who wish to introduce creativity training to engineering curriculum. The models allow educators to comprehend which factors
are most likely to be important or influential, and need to be accounted for when designing the creativity training and introducing it to curriculum.

Chapter 9 will summarise the findings of the thesis and provide conclusions, and detail possible areas for future research.
1.4 How Objectives are addressed in Thesis and Publications

Table 1 details how each of the objectives are addressed in the thesis, and the current state of publication for each objective.

Some of the research outputs address multiple non-consecutive objectives.

Objective descriptions can be observed in section 1.1.

Appendix L provides a more in-depth breakdown of the candidate’s contribution to each of the research publications and in-progress manuscripts, so that this is apparent to the reader.

Table 1: How Objectives are addressed in Thesis and Publications

<table>
<thead>
<tr>
<th>Research Outputs/Papers Title</th>
<th>Journal/Conference Proceedings</th>
<th>Status</th>
<th>Thesis Objective</th>
<th>Chapter Where paper appears in thesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Australian electrical engineering curricula and development of creativity skills: How do we rate?</td>
<td>28th Annual Conference of the Australasian Association for Engineering Education</td>
<td>Published</td>
<td>1</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>2. Creativity in electrical engineering degree programs - where is the content?</td>
<td>Under Revision</td>
<td></td>
<td>1</td>
<td>Chapter 4</td>
</tr>
<tr>
<td>3. Developing creativity and problem solving skills of engineering students: A comparison of web and pen and paper based approaches</td>
<td>European Journal of Engineering Education</td>
<td>Published</td>
<td>2a</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>4. A comparison of web and paper based approaches for idea generation</td>
<td>26th Annual Conference of the Australasian Association for Engineering Education</td>
<td>Published</td>
<td>2a</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>5. Development of creativity of engineering students: a cause for concern?</td>
<td>125th Annual Conference of the American Society for Engineering Education</td>
<td>Published</td>
<td>4b</td>
<td>Chapter 5</td>
</tr>
<tr>
<td>6. Engaging engineering students in creative problem solving tasks: How does it influence future performance?</td>
<td>44th Annual Conference of the European Society for Engineering Education</td>
<td>Published</td>
<td>3</td>
<td>Chapter 6</td>
</tr>
<tr>
<td>7. Perceptions of computer and pen-and-paper based learning environments for engaging in creative problem solving activities</td>
<td>27th Annual Conference of the Australasian Association for Engineering Education</td>
<td>Published</td>
<td>3</td>
<td>Chapter 6</td>
</tr>
<tr>
<td>8. Investigating the presence of a mode-effect on engineering students' self-efficacy during idea generation</td>
<td>Under Review</td>
<td></td>
<td>2b, 4a, 5</td>
<td>Chapter 7</td>
</tr>
</tbody>
</table>
Chapter 2: Literature Review – Creativity in Engineering

It is important to highlight to the reader that the literature review was conducted using a traditional (i.e. “narrative”) style, as opposed to a systematic style.

The snowballing approach was heavily utilised during the literature review. Cited references in the bibliography of an article were regularly accessed and evaluated for their relevance to specific sub-topics, in an iterative manner.

Databases which were utilised included in construction of the literature review were primarily SCOPUS and Web of Science.

2.1 The Need for Creativity and Thinking Skills in Engineering Education

The World Economic Forum is an international non-profit organisation with strategic partners from over 100 of the world’s largest companies including Apple, Google, Ericsson, Siemens, IBM, Microsoft and many others (World Economic Forum, 2018). In 2016, the World Economic Forum (2016) released a report titled “Future of Jobs” which focused on analysing and identifying the skills which businesses would need to be able to remain competitive in the global market, into the future. A focal point of the report was identification of a list of ten primary skills which businesses required in 2015, and the ten skills which businesses would required in 2020. Creativity was identified as an important skill that businesses required both in 2015, and 2020. However, whereas creativity was considered as the tenth most important skill in 2015, this ranking increased to the third most important skill that would be required in 2020. This report highlights the fact that creativity and thinking skills are seen by many of the world’s leading companies as skills that are becoming increasingly important for their employees to possess during this time period.

The need for creativity and innovation skills is acknowledged by the Australian government as being paramount to the success of the Australian business. In 2016 the Australian government launched an inquiry to establish ways in which the Australian tertiary education system may aim to produce a workforce which is focused on creativity and innovation (Commonwealth of Australia, 2017). It was recommended that there was a need for increased focus on STEM (Science, Technology, Engineering and Mathematics) subjects in pre-tertiary education. Regarding the field of engineering in tertiary institutions, it was concluded that there was a need to ensure mathematics was included as a pre-requisite for tertiary undergraduate courses (Commonwealth of Australia, 2017, p. 92). However, there was an apparent lack of further recommendations for how the creativity and innovation skills of engineering students may be enhanced in Australian tertiary education.

Specifically related to the domain of engineering, the need for engineering graduates to possess creativity and innovation skills has been widely acknowledged in reports and studies conducted worldwide. Reflecting upon the skills which engineering graduates of 2020 would need to possess, the United States National Academy of Engineering reported creativity “is an indispensable quality for engineering” and that it is a key skill which professional engineers
Chapter 2: Literature Review – Creativity in Engineering

would need to be able to effectively demonstrate into the future (National Academy of Engineering, 2005). Similar assertions have also been made by the Royal Academy of Engineering in the United Kingdom. It was reported that there was a need for tertiary institutions of the United Kingdom to produce, and industry to employ, engineering graduates who are able to effectively show creativity skills, in order for industry to be able to meet the requirements of professional engineers in the 21st century. The need for the Australian engineering industry to show creativity and innovation has also been highlighted by Engineers Australia, who report that the engineering industry is key to Australia’s “ambition of becoming an innovative and globally competitive nation” (Kaspura, 2017).

Academic studies have also highlighted the importance that professional engineers and engineering employers place upon creativity and innovation. A study conducted by Male, Bush, and Chapman (2009a) investigated the perceptions of 300 engineering graduates about the importance of various competencies for graduates in Australia. It was reported that creativity was rated as an attribute which was important for work as a professional engineer. A further Australian study investigated the importance that engineering employers placed upon ten nominated graduate attributes, that engineering graduates of a specific tertiary institution were expected to possess (Nair, Patil, & Mertova, 2009). Graduates’ ability to develop new or innovative ideas was rated as being important by the engineering employers, although it should be noted that attribute was only rated as the eight most important out of the list of ten nominated attributes (Nair et al., 2009). Similarly, a study which investigated the perceptions of various stakeholders from the field of engineering and computer science about the importance of various employability skills (54 graduates, 26 employers, and academics), established that all groups positively considered creativity and innovative thinking skills as being important for graduates (Wickramasinghe & Perera, 2010).

This apparent need for engineering students and graduates to possess and demonstrate creativity and innovation skills can be specifically linked to the competency standards that are presented by the engineering accreditation bodies of Australia and New Zealand; Engineers Australia and Engineering New Zealand. The stage 1 competency standard for a professional engineer (expected of a graduate engineer) as set out by Engineers Australia (2017d) specifically notes that professional engineers must demonstrate a “creative, innovative and proactive demeanour”. This need to demonstrate creativity remains an integral skill that an engineer must continue to develop as they acquire more professional experience. The stage 2 competency standards by Engineers Australia (2014) outline the skills that an advanced engineer (aimed towards leaders and managers) is expected to possess. The stage 2 competency standard notes that “creativity and innovation” is a key competency of advanced engineers, and that they must “cultivate an attitude of innovation and creativity to add value for clients or sponsors of the service, process or system” (Engineers Australia, 2014). Likewise, Engineering New Zealand requires that professional engineers must “demonstrate creativity when proposing solutions” to complex engineering problems (Engineering New Zealand, 2017). This shows that engineering accreditation bodies consider creativity is an important skill for professional engineers of all experience levels to possess, and it is
important that engineering programs which are accredited by these organisations do effectively develop creativity skills.

The importance of fostering creativity and innovation within engineering education is acknowledged at the highest level by tertiary engineering departments within Australia. In a report addressing the skills which Australian engineering graduates would require in the 21st century, the Australian Council of Engineering Deans stated that Australian “engineering programs have a strong emphasis on ... creativity problem solving and innovation” (King, 2008, p. v). As a result, it is clear that engineering departments of tertiary instructions are highly aware of the need to endure students effectively build upon their creativity and innovation skills, and that institutions assert that their courses effectively ensure this is the case.

2.2 Definition of Creativity
Throughout the past one hundred years or so, numerous definitions of creativity have been provided or proposed by researchers. In a report which highlighted the state of engineering education in the United States one hundred years ago, Mann (1918, p. 74) contended that a person who was creative was ‘original’. Since then, the plethora of creativity definitions which have been provided have created debates, confusion and some misconceptions about what ‘creativity’ actually means. This has made it difficult to address the topic of creativity with clarity in some instances, while ensuring that the meaning of creativity is comprehended by all.

In 1961, Mel Rhodes introduced the 4 P’s model of creativity (Rhodes, 1961). Since then, the model has been one of the most widely used models when exploring and explaining aspects of creativity (Gruszka & Tang, 2017). In brief, the 4 P’s model of creativity suggests that there are four “strands” which relate to, and may influence, creativity. The four P’s are defined as follows (Rhodes, 1961):

- Person – “pertains essentially to the person as a human being”
- Process – “pertains to the mental processes that are operative in creating ideas”
- Press – “pertains to the influence of the ecological press on the person and upon his mental processes”
- Products – “pertains to ideas”

Each of the 4 P’s covers fundamentally different aspects that may influence creativity. Regarding the definition of creativity, the model is important because a lot of recent literature on creativity has built upon this work, and it demonstrates that the definition may change depending on what exactly is being considered or evaluated. For example, the definition of creativity may change when discussing a person, as opposed to a product. This aims to serve as a basis for the reader to understand the wide-ranging literature on creativity which will be discussed in sections 2.2-2.4.

2.2.1 Definition of What Makes Something Creative
Some definitions of creativity are relatively straightforward to interpret, but are limited in their ability to explore the overall creative process. A common example of this is that
creativity is defined as the process of generating ideas, and that a creative person or group is one which generates many ideas (Adánez, 2005). Cropley (2015b) defines that creativity is linked to the capability to generate ideas that are novel and unobvious when faced with a problem which is unfamiliar. Creativity is defined by Amabile (1996) as the generation of ideas or products which are novel and useful.

It is important to reflect upon these definitions and note that arguably, they are defining creativity based upon how it should be measure (the metrics). This demonstrates that many researchers may define or interpret creativity as what makes an object or outcome creative, as opposed to focusing on what exactly creativity as a process actually means.

2.2.2 Standard Definition of Creativity
In an effort to address the problem that there are many definitions of creativity, Runco and Jaeger (2012) attempted to identify what may be considered as the first “standardised definition” of creativity. Reflecting upon the progress of creativity work since the 1930’s, Runco and Jaeger (2012) credit Stein (1953) with proposing the first standardised definition of creativity which involved unambiguous wording. Stein (1953) writes that: “The creative work is a novel work that is accepted as tenable or useful or satisfying by a group in some point in time ... [novel means] that the creative product did not exist previously in precisely the same form ... The extent to which a work is novel depends on the extent to which it deviates from the traditional or the status quo. This may well depend on the nature of the problem that is attacked, the fund of knowledge or experience that exists in the field at the time, and the characteristics of the creative individual and those of the individuals with whom he [or she] is communicating.”

In response, Runco and Jaeger (2012) contend that ideas and products are creative if they are original, and are useful.

2.2.3 Creativity is Domain Dependant
Research has demonstrated that creativity is domain dependant (Baer, 2015), and that having a high level of creativity in one domain does not mean that creativity will be transferred to other domains (Baer, 2012). D. H. Cropley and A. J. Cropley (2005) contend that there are aspects of creativity which are shared across all domains, but that “creativity in engineering clearly differs from creativity in, for example, fine arts”. It can therefore be reasoned that measurement and definitions of creativity should be specific to the domain of interest.

Reflecting upon the domain-specificity of creativity, (Belski, 2017) proposed the following definition of creativity as it relates to the domain of engineering: “Engineering creativity is the ability to generate novel solution ideas for open-ended problems, ideas that are not obvious to experts in a particular engineering discipline and that are considered by them as potentially useful”.

Overall, it is apparent that creativity focuses on the process of generating of solution idea(s) which are considered as potentially useful for resolving the problem being faced, and which are also not obvious existing ways of resolving the problem (i.e. they are novel or original).
On the other hand, the definition of whether something is creative appears to be different, as it focuses on evaluating certain aspects about a ‘thing’ (i.e. a product, a person or a process) in comparison to other things of the same type.

2.3 Measuring Creativity

In the same way that numerous definitions of creativity have been provided by researchers, numerous tests have been developed with the aim of measuring or assessing creativity. Torrance and Goff (1989) found that there were over two hundred and fifty tools which had been developed for the purpose of assessing creativity up until that point. More recently, in a literature review which assessed over half a century of research into creativity tests, Thys, Sabbe, and De Hert (2014) evaluated that over one hundred and ten tools had been developed for measuring creativity. These reviews highlight that there are many specific tools which have been developed for measuring creativity, as each is designed to measure certain traits or characteristics related to creativity which may not be covered by other tools, or may not be appropriate for the specific context.

As previously discussed, creativity is domain dependant (Baer, 2015), meaning that tools and metrics for measuring creativity are likely to vary based upon the context. A person who has extensive experience in creative figure skating may be able to accurately evaluate the creativity of figure skating, but it is unlikely that they will be able to accurately evaluate products from the fine arts without relevant expertise. Likewise, a tool which is developed for measuring the creativity of figure skating is unlikely to be suitable for evaluating the creativity of products from the fine arts, or engineering.

2.3.1 Dimensions of Divergent Thinking and Evaluation of Creativity

In order to be able to measure any form of creativity, identification of appropriate metrics is first required. While some measurement tools or studies use metrics which are specific to the tool or study being considered, there are several metrics which are widely utilised across tools and studies which assess and evaluate creativity. It is important to note that evaluation of some of these metrics is more subjective than others, and therefore the way in which some of these metrics are evaluated may be slightly different, despite the fact that study authors may use the same name for the metric. This section will discuss several of these widely used metrics, and how they relate to divergent thinking and creativity.

Four of the most widely used metrics are fluency, flexibility, originality, and elaboration. Although not necessarily the first to use these metrics, Guilford (1956) was one of the first to classify these metrics as factors which were important for divergent thinking. Since then, many aptitude tests which utilise these metrics have been developed and numerous studies have utilised these metrics to assess creative performance. Urban (1991) states that fluency, flexibility, originality and elaboration are “substantial components of the creative process, but may not be seen synonymously with creativity”. Contradicting this viewpoint is Cropley (2015a, p. 55), who states that creativity is characterised by these dimensions of divergent thinking, and in order to successfully produce solutions, a person must be free from constraints as much as possible (i.e. time, cost, technology). Cropley (2015a, p. 55) concludes that “the only way that we hope to identify and develop effective, competitive, technological
solutions to engineering problems is to explore the largest possible design space—that is, to maximize fluency, flexibility, originality, and elaboration”.

**Fluency** refers to the number of relevant (not necessarily useful) responses which are given in regards to the problem being resolved (Charyton & Merrill, 2009; Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005; Cropley, 2015a; Treffinger, Isaksen, & Stead-Dorval, 2006, p. 55). Fluency can be established by simply counting the number of ideas (Cropley, 2000), meaning it is relatively non-subjective. Examples of studies which include evaluating creativity based on fluency include Adánez (2005); Ames and Runco (2005); Belski, Hourani, Valentine, and Belski (2014); Bouchard (1972); Del Missier, Visentini, and Mäntylä (2015); Dewett and Gruys (2007); Hao, Wu, Runco, and Pina (2015); Nazzal (2015); Reiter-Palmon and Arreola (2015); Saad, Cleveland, and Ho (2015); Shaw, Arnason, and Belardo (1993).

**Flexibility** refers to the variety (Treffinger et al., 2006, p. 55), different types (Cropley, 2015a), or number of categories (Charyton & Merrill, 2009; Cramond et al., 2005) which are used to generate responses. Like fluency, flexibility can also be established by simply counting the number of categories (Cropley, 2000), meaning it is relatively non-subjective. Examples of studies which include evaluating creativity based on flexibility include Adánez (2005); Hao et al. (2015); Reiter-Palmon and Arreola (2015); Shaw et al. (1993).

**Originality** refers to how rare or unusual (Cropley, 2015a) an idea is based upon the number of times which other people have already suggested it (Cramond et al., 2005; Treffinger et al., 2006, p. 55), this is, whether it is statistically infrequent (Cramond et al., 2005; Cropley, 2000). Originality may be evaluated through the use of statistical methods. Alternatively, originality may be rated on a scale, such as a Likert Scale (Cropley, 2000). In order to increase validity when a scale is used for evaluation, experts from the field may be engaged for evaluation using a method such as the Consensual Assessment Technique. Examples of studies which include evaluating creativity based on originality include Adánez (2005); (Charyton & Merrill, 2009); Hao et al. (2015); Reiter-Palmon and Arreola (2015); Shaw et al. (1993); (Treffinger et al., 2006).

**Elaboration** refers to the level of detail or number of details which are provided (Cramond et al., 2005; Treffinger et al., 2006, p. 55). Evaluation of elaboration is ultimately subjective, and may be evaluated based upon methods such as use of a Likert Scale. Examples of studies which include evaluating creativity based on elaboration include Adánez (2005); Reinig and Briggs (2008); Reiter-Palmon and Arreola (2015); Saad et al. (2015).

By using these metrics, it is possible to evaluate divergent thinking and creativity in a number of contexts. For example, Charyton and Merrill (2009) specifically utilise fluency, flexibility and originality for evaluating creativity in the context of engineering design, agreeing with the viewpoint of Cropley (2015a, p. 55), minus the inclusion of elaboration. Meanwhile, Belski (2017) contests that engineering creativity may be measured in the context of solving open-ended problems by engaging subjects in generating ideas and evaluating the number of independent ideas (akin to fluency) and breadth of ideas (analogous to flexibility). Overall, it is apparent that these dimensions of divergent thinking are widely utilised for assessing creativity, including within the domain of engineering.
2.3.2 Use of ‘Quality’ in Evaluating Creativity
Ideas or products may also be rated according to their ‘quality’, usually through use of a scale (such as Likert Scale), on which experts judges are requested to independently evaluate the products. Methods such as the Consensual Assessment Technique may then be used to check for agreement between the expert judges, and verify that the product is of high quality if the level of agreement between the judges.

However, while it is important to assess quality in certain situations, it is important to discuss that evaluating idea quality is a process which focuses on the use of convergent thinking skills, as opposed to divergent thinking skills. Referring to the four stages of creative problem-solving as detailed by Cropley (2015a, p. 43) (problem recognition, idea generation, idea evaluation, and solution validation), it is clear that this process actually conforms to the idea evaluation stage, as opposed to the idea generation stage, and focuses on the use of convergent thinking skills as opposed to divergent thinking skills.

Another issue is that the definition of quality and how it is rated may change depending on the study being considered. For example, Nazzal (2015) evaluated the ‘quality’ of students’ overall performance during the idea generation phase in an engineering design context, based upon use of a scale and the Consensual Assessment Technique. In other words, Nazzal (2015) rated quality of the overall ideation phase, as opposed the quality of each individual idea. When rating the quality of each individual idea, Saad et al. (2015) referred to quality as the ‘originality’ of each idea. Other studies have also linked the quality of each individual idea to ‘solution effectiveness’ (McLeod, Lobel, & Cox Jr, 1996) or even ‘originality’ and ‘feasibility’ (Diehl & Stroebe, 1991).

While evaluating idea quality is important in some cases, it is arguable that it is not when focusing on divergent thinking. Clearly, this makes it difficult to compare the quality of ideas between studies, unless the same definition of quality, and method for evaluating it are the same in both studies. In response to the wide array of methods for assessing idea quality, Saad et al. (2015) concludes that “the plethora of methods for assessing idea quality explains why the findings are equivocal when compared against idea quantity results”.

2.3.3 Tools for Evaluating Creativity
In addition to the fact that there are hundreds of tools for measuring creativity (Torrance & Goff, 1989), there is also the issue that such tools may be categorised in different ways by different researchers. Cropley (2000) contests that creativity tests may be categorised into one of three primary categories; creative products, the creative process, and the creative person. Upon reviewing the various types of creativity measures which exist, Reiter-Palmon and Arreola (2015) summarised that were eight different types of creativity measures including creative personality, creative accomplishments, creative behaviours, creative self-assessment, creative problem-solving, divergent thinking and the creative product.

This section will discuss some of the tool which exists for measuring creativity, in order to provide context about the different types of tools which exist. The categories covered below are adapted from those outlined by Cropley (2000).
2.3.3.1 Creative Products

Products or ideas that are generated by a person or machine can be assessed in terms of whether they may be considered as being creative or not. A creative product may be considered as a product that has deemed to fit various descriptions such as novel, original, unusual, or non-obvious. Various models have been proposed as ways to measure the creativity of a product or work. For example, the Creative Solution Diagnosis Scale (CSDS) was introduced by D. H. Cropley and A. J. Cropley (2005) as a way to measure the creativity of a problem solution. Four dimensions are used in the scale to assess creativity: relevance and effectiveness, novelty, elegance, generalisability. Products are categorised as either routine, original, elegant, or innovative depending with whether certain dimensions are regarded positively or not (D. H. Cropley & A. J. Cropley, 2005).

The Taxonomy of Creative Design proposed by Nilsson (2011) suggests a framework that products can be classified into one of five categories: imitation, variation, combination, transformation, and original creation. The imitation category references that the product is the same or very similar as something which already exists, variation infers that the product is only slightly different to what already exists, while combination refers to the action of taking two existing products and combining them in some way, taking some characteristics form each product (Nilsson, 2011). The transformation category covers products which exist but have been re-created in another form (e.g. a movie which is adapted from a stage play), while an original creation is a product which shares no clear characteristics with an existing product (Nilsson, 2011). Original creations are considered as being most creative in the framework. However, other researchers such as Albert (1990), have reached conclusions which suggest that it is there are significant challenges in attempting to objectively define the creativity of a product, because any such process is inherently too subjective and open to interpretation.

Products may also be rated for their creativity through use of the Consensual Assessment Technique (Amabile, 1982). The Consensual Assessment Technique is based upon the assertion that “a product or response is creative to the extent that appropriate observers independently agree it is creative” (Amabile, 1982). In other words, the technique considers that a product is creative if several expert evaluators, who have extensive experience and relevant knowledge of the field, agree that it is. If evaluators disagree on whether the product is creative, it is difficult to assert that the product. Creativity is often rated by evaluators using a scale, such as the 5-point Likert Scale. When utilising the technique it is important that the evaluators have a high level of expertise relevant to the field. Research has demonstrated that novices (non-experts) tend to have a much lower level of agreement than those who are experienced in the field. For example, a study by Kaufman, Baer, Cole, and Sexton (2008) asked 10 experts (established poets with multiple published books of poetry) and 106 non-experts (college students) to rate the creativity of 205 poems. It was found that non-experts on average awarded a higher creativity rating to the poems than the experts, and that the level of agreement (based upon inter-rater reliability) between non-experts was lower than that of the experts.
2.3.3.2 Creative Potential
Creative potential relates to the level of creativity skills which a person intrinsically possesses, or their general level of creativity compared to a specified population. Creative potential can be measured through means including psychometric tests, such as the Torrance Test of Creative Thinking (TTCT) (Torrance, 1966), and tools which measured peoples’ self-perceptions of their own creativity, such as the Khatena-Torrence Creative Perception Inventory (KTCPI) (Khatena & E.P., 1976). The Torrance Test of Creative Thinking incorporates several tasks which are categorised as either verbal, or non-verbal (Torrance, 1966) (also known as figural, or pictorial). A person is evaluated based upon metrics including fluency, flexibility, originality and elaboration. Performance in these several tasks can be used to calculate an overall Creativity Quotient. This allows a person’s creativity to be compared to that of a specified population, analogous to how an intelligence test can be used to calculate an Intelligence Quotient and be used to compare intelligence to that of a specified population.

The Khatena-Torrence Creative Perception Inventory is based upon the notion that a person’s perception of their creativity is related to whether the person can be expected to behave in a creative manner (Khatena, 1977). The inventory incorporates two measures of creative perceptions (called Something About Myself and What Kind of Person Are You?) which each measure a person’s creative perceptions in a different way (Khatena, 1977). Each of the two measures contains 50 items which allows a total score out of 100 to be established, by allocating one mark to each correct answer (Khatena, 1977). Although measures of creative potential can provide insight into how creative a person is compared to those around them in the population, it does not necessarily allow measurement of how well a person performs in a task which is specifically related to their field of study, as the tasks are usually specified by the formal test being used (such as TTCT, KTCPI).

2.3.3.3 Creative Ability
Tests which assess the creative ability refer to those which evaluate the level of achievement or performance that is demonstrated by a person during completion of a specified problem. Such tasks can be from aptitude tests such as Guilford’s Alternative Uses Task (Gilhooly, Fioratou, Anthony, & Wynn, 2007), the Remote Associated Test (Mednick, 1968), sub-tasks of the Torrence Test of Creative Thinking, or any other ill-defined task which a person may be faced with.

2.4 Theories of Creativity

2.4.1 Introduction
In addition to tools which have been developed for measuring creativity outlined in section 2.3, several theories which attempt to explain aspects about the creative process. This may include things such as the steps which a person needs to follow to be creative, or the skills or knowledge that are required in order to be creative.

Theories on creativity can be categorised as either factorial theories, associative theories, stage theories, miscellaneous theories, or a combination which crosses into several categories.
(Wang & Nickerson, 2017). Factorial theories outline factors which influence the creativity of individuals, groups, or organisations. Associate theories of creativity argue that “creativity is the process of combining mental elements and associative thinking can connect mental elements” (Wang & Nickerson, 2017). Stage theories discuss the stages of the creative process, including how many stages there are, what they each involve, and how they interrelate.

A study by Wang and Nickerson (2017) which included a review of theories of creativity highlighted a total of 5 factorial theories, 2 associative theories, 5 stage theories, and 3 miscellaneous theories.

### 2.4.2 Componential Theory of Creativity

The Componential Theory of Creativity is a factorial theory of creativity which includes aspects related to stages of the creative process, therefore arguably categorising as a stage theory as well. The theory is one of the most widely accepted and utilised theories for explaining creativity, having been cited over two thousand times (Amabile, 2013).

![Componential Theory of Creativity Diagram](image)

**Figure 1: Componential framework of creativity.** Broken lines indicate the influence of particular factors on others. Solid lines indicate the sequence of steps in the process. Only direct and primary influences are depicted here (Amabile (1983)).

Figure 1 depicts the Componential Theory of Creativity, as set out by Amabile (1983). The theory provides a framework which in the words of Amabile (1983), “describes the way in which cognitive abilities, personality characteristics, and social factors might contribute to different stages of the creative process”. An underlying concept of the theory regards the notion that an individual’s level of creativity will vary at different points of time. At any certain point in time, an individual’s level of creativity is influenced by several factors that are within the person, and around the person (Amabile, 2013).
The Componential Theory of Creativity outlines three primary components within the individual that influence their creativity level at any given time. These are domain-relevant skills, creativity-relevant skills, and task motivation (Amabile, 1983). In addition, there is one component outside the individual that influences their creativity level at any given time; the social environment. As shown in Figure 1, the social environment influences the individual’s Task Motivation which in turn influences their ability to be creative at the given point in time. As is clear from the Componential Theory of Creativity framework, creativity is a complex phenomenon incorporating a process of several stages, upon which there are numerous factors which can influence the process.

![Figure 2: Components of creative performance. Source: Amabile (1983).](image)

Figure 2 details the entities/skills which have an influence on the primary factors outlined in the Componential Theory of Creativity. These skills include domain-relevant skills, creativity-relevant skills, and task motivation. Engineering degrees already have a large focus on the inclusion of domain-relevant skills. This suggests that efforts to enhance students’ creativity should be focused on enhancing creativity-relevant skills, and task motivation.

In a recent study, Belski, Skiadopoulos, Aranda-Mena, Cascini, and Russo (2018) suggest that there is a need to expand and update the Componential Theory of Creativity incorporate the component of general knowledge from outside the domain of expertise. This suggests that expanding one’s knowledge of topics outside their field of expertise may positively influence their creative abilities. Within an engineering degree, students may be encouraged to study electives from areas other than their chosen domain. In turn, this will help to broaden their general knowledge, possibly enhancing their variety of long-term knowledge from which they can draw analogies and generate creative ideas (Belski & Belski, 2008).

Creativity skills refer to the knowledge and experience that an individual has that are related to creativity, as well as their personality characteristics. As can be observed, creativity-relevant skills include “knowledge of heuristics for generating novel ideas” which is dependent on training and previous experience in idea generation. One way to obtain experience and knowledge of ideation heuristics is through creativity training which is discussed below in section 2.8. Likewise, a person who places high value on creativity or
considers themselves to be very creative, are more likely to possess skills which allow them to be creative.

Task motivation refers to the level of motivation which a person possesses to undertake a specific task at a specific point in time. It is possible that a person may complete a certain task at close two points in time (when their knowledge and experience are very similar), and yet they will perform differently due to their level of motivation. Task motivation is based upon several factors including the individual’s intrinsic motivation, external factors in the social environment and the individual’s ability to minimise negative external factors. Intrinsic motivation can change drastically depending on circumstances which are influencing the individual. If the individual is tired, is unwell, or is facing personal issues, it is likely that their concentration and motivation will decrease, thus leading to a decrease in creativity which makes sense. External factors can include incentives or punishments for performing ineffectively. Factors such as the importance or value which is placed upon creativity by a workplace or school may also act as external factors. If a person works or studies in an environment which encourages creativity, it is more likely that this will entice the person to be creative. Motivation in general is highly correlated with task performance, regardless of the domain in which the problem resides (Schunk, 1995) Self-efficacy is a major factor which can influence Task Motivation, and will be discussed in section 2.4.3.

The Componential Theory of Creativity suggests that positive efforts to improve students’ creative capacity may be at least partially enhanced through identifying ways of improving their idea generation capability. One approach for doing this would be to include coursework which focuses on providing explicit training in the use of appropriate heuristics throughout the duration of studying an engineering degree (i.e. creativity training) which is discussed below in section 2.8.

2.4.3 Self-Efficacy

Formalised as a concept by Bandura (1977), self-efficacy was defined as ‘People's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances’ Self-efficacy can be defined as the confidence which a person has to resolve a specific problem they are facing (Artino, 2012; Schunk, 1995). Regardless of the domain in which a problem lies, research has demonstrated that that a person’s self-efficacy strongly and positively predicts their motivation and performance (Schunk, 1995). Reflecting upon the Componential Theory of Creativity, it is clear that self-efficacy is linked to creative performance. The self-efficacy which a person possesses will influence their Task Motivation which in turn will influence the person’s creativity performance. This connection between creative self-efficacy and creative performance is reflected in the findings of a review of empirical studies carried out by Puente-Díaz (2016). Puente-Díaz (2016) identified that there was a positive link between creative self-efficacy and creative outcomes, demonstrating the importance of self-efficacy in relation to creativity.

Like all other domains, self-efficacy is very important within engineering. Harlim and Belski (2015) established that self-efficacy is vital for being willing to engage in unfamiliar problems within engineering, and that self-efficacy is linked to the development of future
problem-solving skills. However, studying an engineering program does not necessarily enhance the self-efficacy of students to engage in problem solving. Steiner et al. (2011) reported the concerning findings that the self-efficacy of engineering students actually declined between first and fourth years of study during an undergraduate degree. When considered alongside studies which report that engineering students lack confidence in creativity skills (Gardener, Goldfinch, & Willey, 2017), it is imperative that courses which include creativity training must also aim to enhance self-efficacy.

2.5 Is There An Issue in Engineering Education with Developing Creativity Skills?

2.5.1 Introduction
Despite the apparent importance that is placed upon developing creativity and innovation skills in tertiary engineering situations, research has unfortunately presented conflicting results as to whether students actually do enhance their skills throughout completing an engineering program of study. While some studies do demonstrate that the creativity of engineering students does increase over the period of time taken to complete an engineering program of study (usually four years full time duration), other studies report that creativity actually decreases. While studies may utilise different metrics of assessment which may partly account for part of this discrepancy, findings that creativity may decrease when studying an engineering program highlight an issue which must be further investigated. Other issues are also evident in the literature, such as the disconnect between some educators asserting that they do include course material which helps to build creativity skills, while their students may perceive that the same material did not do anything to increase their creativity skills or did not even realise that the material was meant to address creativity skills (Kazerounian & Foley, 2007).

This section will present several of the positives and negatives that are present in engineering education according the literature, and how these issues may influence the extent to which engineering curricula is conducive to fostering creativity skills of students.

2.5.2 Measured Enhancement or Decline in Engineering Students’ Creativity Skills
Several studies have compared the creativity and innovation skills of first and fourth year undergraduate students, in order to establish how these skills may change over time as a result of studying an undergraduate engineering degree. Nazzal (2015) compared the creative performance of first, second, third and fourth year engineering students enrolled at an American tertiary institution during various stages of the creative problem-solving process (problem recognition, idea generation, idea evaluation, and solution), when presented with an ill-defined engineering related problem. Creativity was evaluated in each stage based upon use of the Consensual Assessment Technique (Amabile, 1982). Overall, it was established that the creativity level of first year students was overall significantly lower than students who were in their second, third and fourth years of study. Moreover, it was noted that first year students found it hard to consider or generate ideas that were varied in nature, whereas students in their later years of study were able to conceptualise ideas which may fit into a
wider array of categories, or may require utilisation of a greater number of areas of knowledge to generate (Nazzal, 2015).

A study of American undergraduate engineering students found that upon reflection, fourth year engineering students rated (on 5-point Likert scale) their own capabilities for innovation at a level which was statistically significantly higher than the level at which first year students rated their own ability for innovation (Davis & Amelink, 2016). This result suggests that the confidence of the fourth year students to engage in creative activities was higher at the end of their program of study than it would have been when they started their program of study. It follows that students’ ability to be creative was likely successfully enhanced over the period taken to complete the program of study. Overall, these studies provide evidence that students’ creativity skills can be successfully enhanced over the four year period taken to study an engineering degree, according to both students’ measured creative performance, and students’ own perceptions of their abilities. However, other studies have reached conclusions which contradict these findings.

Genco, Hölttä-Otto, and Seepersad (2012) investigated the innovation capabilities of undergraduate engineering students in their first and fourth years of study by means of an experiment. In the study, students were presented with an engineering problem (developing a next-generation alarm clock) and asked to generate solution ideas using a specified method (6-3-5/C-sketch method). The solution ideas were then rated for their level of originality and innovation. Perhaps surprisingly, it was established that overall, first year students proposed ideas which were more rated as being more innovative than their fourth year counterparts. Apparent decline in students’ measured creativity and innovation skills between their first and fourth years of study has not been limited to experimental studies; it has also been observed through other means. An investigation into the creative and critical thinking capabilities of first year and fourth year students used applicable psychometric tests to establish the skill levels of students (Sola, Hoekstra, Fiore, & McCauley, 2017). Sola et al. (2017) found that although the critical thinking skills of students remained similar between first and fourth years of study, students’ creative thinking skills significantly declined between first and fourth years of study. These studies demonstrate the worrying outcome that under certain circumstances, creativity of students may actually decrease throughout studying an undergraduate engineering degree. Such an outcome would mean that graduates’ creativity skills would be unlikely to meet the expectations of accreditation bodies such as Engineers Australia (2017d).

2.5.3 Factors Influencing the Creativity of Engineering Cohorts
There are several potential attributing factors highlighted within the literature as to why the creativity of some engineering students may not only remain similar throughout studying a degree, but potentially decline. In order for the creativity of students to be enhanced, it is imperative that they possess motivation and place value upon the idea of studying about the topic of creativity. A person’s value and attitude towards creativity are predictive of the real behaviour that the person is likely to possess (Acar & Runco, 2014). In other words, if a person places higher value on creativity, they are more likely to be inclined to spend time improving related skills.
Researching the value which engineering students place upon the value of creativity in engineering education, Waller and Strong (2017) established that students of all year levels between (and inclusive) first and fourth years of study considered creativity was valuable in engineering education. The study incorporated the viewpoints of between 108-152 people from each year level. However, while students from first, second and third years of study all valued creativity at a level which remained constant, this diminished when compared to students in fourth year and above. Results showed that the value placed upon creativity by students in their fourth year of study and above, was significantly lower than that from any other year level. This suggests that students in their fourth year of study may be less inclined to devote time to developing creativity and innovation skills.

Reasoning for this apparent decline in the value that is placed on creativity by students in their fourth year of study may be reflected in the findings of Atwood and Pretz (2016). Atwood and Pretz (2016) established that engineering students, who possessed higher confidence in their creative abilities at the start of their undergraduate program of study, were less likely to complete their program of study and graduate. If reflective of engineering curricula, this outcome suggests that there is likely to be something about the structure of engineering curricula which may disenfranchise creative students. It is possible that engineering curricula does not provide creative students will sufficient opportunity to utilise their skills effectively, contributing to any decrease in creativity which may be observed in a cohort.

2.6 Coverage of Creativity Material in Engineering Education

Research has highlighted that there is a general lack of creativity-related material in engineering curricula, based both upon studies which have conducted analysis of engineering programs or courses, and studies which have investigated the perceptions of students and academics.

2.6.1 Measured Coverage of Creativity in Engineering Curricula

Previous studies in the existing literature have highlighted that course material on the topics of creativity and innovation are generally lacking in engineering education. Creativity is usually given very low priority, and inclusion of creativity material within engineering curricula is rare.

For example, one study conducted at a mid-western American college investigated the discrepancy between situations where course instructors had specifically included the goal of enhancing creativity in their course learning outcomes, and whether was actually designed in a way that would actually lead to increased creativity skills in students (Daly, Mosyjowski, & Seifert, 2014). In total, the content of seven engineering courses were thoroughly evaluated. Analysis demonstrated that there was a clear inclusion of course material which focused on developing convergent thinking skills (perhaps inadvertently on the part of the educators), but course content focused on the development of divergent thinking and creativity skills was lacking. Specific issues that were highlighted included a lack of opportunities for exploring and devising alternative solution ideas, a lack of instructional material covering the generation of alternative solution ideas (Daly et al., 2014).
A comprehensive study by Marquis, Radan, and Liu (2017) analysed the coverage of creativity material within the course outlines of over one thousand courses from a Canadian tertiary institution. All publicly accessible course outlines from several disciplines of study were evaluated, including engineering, business, science, and social science. The contents of one hundred and forty nine engineering course outlines were evaluated, building a comprehensive picture of how engineering courses built creativity skills at the institution. Despite that the “study university has explicitly recognized creativity as a central part of its mission and vision”, it was established that coverage of creativity material within the one hundred and forty nine engineering courses was incredibly limited. More specifically, only one of the engineering courses explicitly referred to creativity within the course outline, highlighting the low importance that was placed on creativity within engineering (Marquis et al., 2017).

These studies highlight that engineering institutions, curricula designers and individual educators may place value upon creativity and consider it as a skill that is worth developing in engineering students. Stakeholders may have good intentions of implementing course material which is aimed at developing creativity skills. However, it is clear that implementation of these objectives within engineering courses is not always done in a proper manner, and that various engineering education stakeholders within tertiary institutions differently comprehend what building creativity skills refers to. Overall, it is apparent that just because stakeholders may claim engineering programs or courses build creativity skills, does not mean this is assertion will be regarded as accurate when the contents of the courses are analysed.

2.6.2 Perceptions about Coverage of Creativity in Engineering Curricula
This apparent lack of creativity related material within engineering curricula is reflected in studies which have investigated student’s perceptions of the coverage of creativity in engineering curricula. Martin-Erro, Escudero, and Somonte (2016) found that 82% of engineering students and 79% of engineering academics disagreed with the statement that creativity was sufficiently addressed in engineering curricula, while 59% of participants agreed that there were no courses which covered creativity within the program of study. Reflecting on the importance of creativity as a skill for innovation, Gaudron and Kövesi (2017) found that engineering students considered creativity was a very important skill for innovation. However, students reported that their engineering program of study suffered from a critical lack of creativity related material.

Research has also demonstrated that engineering students perceive that their program of study is less effective at building their creativity skills than students from other domains of study. Daly, Mosyjowski, Oprea, Huang-Saad, and Seifert (2016) compared the perceptions of students enrolled within education, humanities, social science, arts, and engineering programs, to understand whether students judged that their creativity skills were influenced in different ways based upon choice of study program. Analysis showed that engineering students perceived their program of study as having little influence on their creativity skills, indicating that in the opinion of engineering students, their program of study did little to build their creativity skills. In contrast to students from other domains, results were discouraging for engineering. The engineering students perceived that their program of study
had less effect on their creativity skills than students from any other discipline that were investigated (Daly, Mosyjowski, et al., 2016).

A further study conducted at a mid-western American tertiary institution investigated the differences in perceptions of engineering teaching staff and fourth year engineering students towards the way in which creativity was covered within the engineering program of study (Carpenter, 2016). All of the engineering teaching staff who were interviewed during the study asserted that their course was effective at building creativity skills. In contrast, during the interviews that were conducted with the engineering students, Carpenter (2016) concluded that in the opinion of all the students interviewees, “the mechanical engineering program did little to encourage and develop creative-thinking skills”. This discrepancy in the perceived coverage of creativity-related material between engineering students and teaching staff reflects the findings of Daly et al. (2014) and Marquis et al. (2017). This discrepancy between the perceptions of engineering students and engineering teaching staff are also reflected in the findings of Kazerounian and Foley (2007).

Like Carpenter (2016), Kazerounian and Foley (2007) found that engineering educators asserted that their courses provided students with opportunities to build their creativity skills. In contrast, the engineering students who were enrolled in these courses felt that chances to demonstrate and build creativity were very limited and that creativity was overall given a very low priority. More troubling was the conclusion that many students felt their instructors did not place any value on creativity (Kazerounian & Foley, 2007), showing a clear disparity between what engineering students and teaching staff consider to be development of creativity skills. Overall, Kazerounian and Foley (2007) concluded that engineering curricula was not conducive for building creativity skills in engineering students, and that there were significant obstacles that must be overcome in order to able to do so effectively.

The findings of these studies again reinforce the point that just because engineering educators may claim their courses will build creativity skills, does not mean this is assertion will be regarded as accurate by other stakeholders, or when the contents of the courses are analysed.

This outcomes of Kazerounian and Foley (2007) are reflected in the observations of Mahboub, Portillo, Liu, and Chandraratna (2004), who asserts that “professors often assume that their students develop skills in creative thinking implicitly as a result of taking their design courses. On the other hand, students may struggle with creative problem-solving without any formal training. This frustration seems to be exacerbated when students are assigned open-ended design problems which require creative thinking. Additionally, students and faculty may differ in their understanding of creativity in ways that relate to individual differences and to disciplinary culture”. The fact that the findings of Daly et al. (2014), Marquis et al. (2017), Gaudron and Kövesi (2017) and Carpenter (2016) also agree with this, adds credence that this assertion is likely to be an accurate observation. As a result, there may be a need for engineering educators to establish ways of making it clear to students how and when their courses are aimed at enhancing creativity skills.
2.7 Creativity in the Context of Engineering Problem-solving

2.7.1 Introduction

Problem-solving may be defined as the general process of resolving an issue which a person is faced with. Such issues can vary enormously in complexity. At the simplest level, issues may be categorised into one of two broad classifications. The first regards the situation where the solution that is required for resolving the issue is obvious, clear, or apparent. For example, if a carpenter wishes to drive a crosshead (Phillips-head) screw into a piece of wood, they must engage in the process of problem-solving to deduce how this may occur. Due to their previous experience and knowledge about the topic, the carpenter will very quickly (almost instantaneously) comprehend that a crosshead (or Phillips-head) screwdriver is required to accomplish the task. Another situation may involve a scenario where a person wishes to travel between two locations. Upon consideration, the person may reach the conclusion that they know of several existing solutions which may resolve the problem. Such solutions may involve taking public transport, taking a taxi, or driving themselves to the destination location.

2.7.2 Creative Problem-solving

The second classification regards situations where the solution may not be apparent, obvious, or immediately clear. In order to resolve the issue being faced, a person must conceive a new, or novel solution to resolve the issue. This process closely resembles the definition of creativity posited by Cropley (2015b) which outlines that a persons’ creative ability is linked to their capability to generate ideas that are novel and unobvious when faced with a problem which is unfamiliar. This is a special type of problem-solving which specifically requires the use of creative skills, and is referred to as creative problem-solving (Treffinger et al., 2006).

In reflecting upon the processes of creativity and problem-solving, Cropley (2015a, p. 47) reviewed several general models of the problem-solving process. Drawing upon the work of Guilford (1959), Cropley (2015a, p. 43) concludes that the creative problem-solving process as it pertains to engineering may be modelled as a set of four stages including problem recognition, idea generation, idea evaluation, and solution validation. Cropley (2015a, p. 43) highlights that the problem recognition, idea evaluation, and solution validation stages of creative problem-solving are characteristic of convergent thinking skills. Conversely, Cropley (2015a, p. 43) highlights that the idea generation stage of creative problem-solving is characteristic of divergent thinking skills.

2.7.3 Problem-solving Skills of Engineering Students

Section 2.2.1 highlighted the issue that the creativity and innovation skills of some engineering students do not necessarily increase throughout the four year period (typical in Australia, New Zealand, USA, UK) taken to study an undergraduate engineering degree, and that many students lack confidence in their creative abilities. Wickramasinghe and Perera (2010) found that graduates’ rating of their own creative abilities did not meet the level expected of employers. In considering the creativity and innovation skills of engineering graduates, it is also important to comprehend how these skills may compare to the overall problem-solving skills that are developed by students over completing an engineering degree.
Although completion of an engineering program of study leads to enhancement in the knowledge and problem solving skills of students’, there remains a question of whether the level of these skills actually meets the level that is required by engineering industry and employers. Studies which have investigated the employability of engineering graduates consistently highlight that there is gap between the level of skill which engineering employers expect, and the level of skill which the employers perceive their engineering graduate employees actually possess (Blom & Saeki, 2012; Male, Bush, & Chapman, 2010; Nair, Patil, & Mertova, 2009; Ramadi, Ramadi, & Nasr, 2016; Wickramasinghe & Perera, 2010). Moreover, these studies highlight that the issue is not an isolated issue, but is a global one: the findings are not limited to any specific geographic region and the issue of problem-solving skills affects graduates from many locations.

It is possible that the skill level expected of employers is simply too high, and most students are unable to effectively reach this skill level during their program of study. However, it is apparent that both the creativity and problem-solving skills of engineering graduates do not necessarily meet the expectations of engineering employers. It is important to note that the context of employment must be considered when interpreting these results, as different jobs are likely to require different skill levels.

2.7.4 The Issue of Idea Generation and Fixation

Reflecting on the literature, one of the stages of the engineering problem solving process that students generally have trouble with, or do not necessarily complete effectively, is idea generation (Samuel & Jablokow, 2010). During idea generation, many engineering students can easily become hampered by a phenomenon known as either fixation or cognitive inertia (depending on the context) which can make it hard to develop alternative solution ideas (Condoor, Shankar, Brock, Burger, & Jansson, 1992; Kershaw, Holta-Otto, & Lee, 2011; Samuel & Jablokow, 2010). When presented with a design problem, a person will come up with an initial solution idea. The issue of fixation entails that the person then either finds it hard to consider possible alternative solution ideas (possibly due an inability to shift the focus of their thinking), or for various possible reasons, the person is unwilling to consider other possible solution ideas. This means that the person will then be stuck with their initial (or a certain) solution idea, and will find it hard to conceptualise other solution ideas. This means that solution ideas which may be more effective, efficient, or profitable may be overlooked which can impede a person’s (or a company’s) ability to effective by creative and innovate.

The issue of design fixation can be directly related to creative skills. If a person possess a sufficient level of creativity when trying to resolve the problem, it is likely that they will be able to overcome the issue of being unable to diversify their thinking, and will be able to generate new solution ideas. Therefore, enhancing the creativity skills of engineering students is not only beneficial in terms of general creative performance. It has a specific benefit related to situations encountered during the engineering problem-solving process, when creativity is required.
2.8 The Effectiveness of Formal Creativity Training on Thinking Skills

Section 2.8 will highlight that creativity can be enhanced in a number of different ways through creativity training. It is important to preface this section by mentioning that creativity skills can be built in a large number of ways (see section 2.4), but it is important to understand that the chosen method will be dependent on how one is trying to build creativity skills. For example, gaining domain knowledge is not the same as removing existing barriers to creativity, such as fixation.

Within the scope of this thesis, the aim is to help students overcome the issue of idea fixation specifically though training in creativity techniques.

This section will highlight that TRIZ techniques are one from of creativity training that can be effective at building students’ creativity skills. However, it is imperative to acknowledge that this does not mean that TRIZ tools will always not be a suitable, or the most effective means for building creativity skills.

2.8.1 Influence of Creativity Techniques and Training on Creativity and Ideation

Some of the early studies which focused on evaluating the effectiveness of creativity training investigated the brainstorming technique popularised by Osborn (1953). One area of research investigated whether participants performed more effectively using brainstorming instructions (write down all ideas), compared to non-brainstorming instructions (write down only ‘good’ ideas), as well as whether participants were able to apply the brainstorming technique more effectively when they had received previous instruction in use of the technique compared to when they had received no training in use of the technique (Parnes & Meadow, 1959). Perhaps unsurprisingly, Parnes and Meadow (1959) found that participants were able to generate a higher number of ‘good’ ideas when they were provided with the brainstorming instructions, as opposed to instructions which required listed ideas to be ‘good’. Moreover, it was established that students who had received previous training in the use of the brainstorming technique performed more effectively when using the technique, compared to those who had not previously received training. This set a precedent that exposing students to the brainstorming technique and providing training, were both demonstrated to be ways for students to enhance their ideation performance.

A more recent study by Blomstrom, Boster, Levine, Butler, and Levine (2008) investigated several aspects related to training in the use of brainstorming, including whether training enhanced performance (number of ideas generated), whether providing more (longer duration) training enhanced performance, and whether groups were more effective using the technique than individuals. Regarding the last point, results showed that individuals (nominal groups) outperformed groups (Blomstrom et al., 2008), an phenomenon which has been known for several decades (Diehl & Stroebe, 1991). Results also demonstrated that providing training enhanced participants’ ability to generate more ideas, while providing a higher level of training further helped to enhance participants’ ability to generate ideas.

Considering creativity techniques other than brainstorming, one study evaluated whether exposing engineering students to simple heuristics was able to enhance their ideation
performance (Belski et al., 2014). In the study, first year engineering students were exposed to either no heuristic (control group), Random Word by Edward de Bono (De Bono, 1995) or the Fields of MATCEMIB (Belski, 2007), a TRIZ heuristic. The study focused on an experiment whereby students were engaged in generating ideas for a period of six minutes. Both of the intervention groups were shown eight words over the period of 16 minutes, one word every two minutes. Students exposed to Random Word where shown eight words randomly selected from a dictionary as per the process dictated by (De Bono, 1995), while students of the MATCEMIB group were shown words which make up the acronym (Mechanical, Acoustic, Thermal, Chemical, Magnetic, Intermolecular, Biological). No other instructions were provided to participants. It was reported that students from both intervention groups outperformed the control group, while students from the MATCEMIB group outperformed the Random Word group. Moreover, this experiment was repeated using students from Finland, Russia, and the Czech Republic (I Belski et al., 2015) and Germany (Belski, Livotov, & Mayer, 2016), with outcomes demonstrating that the results had been replicated in each instance. These outcomes demonstrate that in some cases, creativity heuristics can be effective even when a person is merely exposed to them, reflecting the outcomes also demonstrated by Parnes and Meadow (1959). It is apparent that explicit training in use of the associated technique is not always needed, though it usually also helps to enhance performance further.

2.8.2 Influence of Creativity Courses on Creativity and Self-Efficacy

2.8.2.1 Introduction

Building upon the notion that creativity training can influence creative performance, various studies have demonstrated that formal courses which include creativity-related training (usually over a duration of several weeks or a semester), can enhance participants’ creative performance and self-efficacy. Reviewing these studies will demonstrate that it is possible to enhance students’ creativity skills through the use of formal courses which focus on creativity in some manner. Note that a ‘course’ (also referred to as ‘unit’ in some cases) in this section refers to one of the many components which comprise an overall degree or program of study. Many of the studies evaluate the influence of the course on creativity-related metrics, through use of pre and post questionnaires or activities.

Reflecting upon the discussion of self-efficacy and its relation to creative performance and engineering problem-solving in section 2.4.3, it is apparent that there is a need to increase the self-efficacy of students where possible. Therefore, it is important to also reflect upon existing studies which explore the influence of creativity training on self-efficacy.

2.8.2.2 Courses in Domains other than Engineering

Studies conducted by Dewett and Gruys (2007) and Anderson (2006) report outcomes from courses which involved Masters of Business Administration students (N=54 and N=59, respectively) focusing the topic of creativity and innovation in organisations. Dewett and Gruys (2007) engaged participants in reading academic journals, completing projects, and engaging in experiential activities through the course. Participants were asked about their perceptions regarding the importance of creativity, their own creativity skills, and their
creative self-efficacy at the beginning and end of the course, to vague how involvement in the course may have influenced these factors. Results showed that involvement in the course significantly enhanced students’ ideational fluency and creative performance, their willingness to take risks, and their creative self-efficacy. Participants rated the importance of creativity as higher at the end of the course, but the difference was not statistically significant. The course conducted by Anderson (2006) primarily focused on building participants’ “confidence in their own creativity”, by overcoming their fear of failure and taking risks. During the course, students were involved in innovation exercises which were completed using twelve pre-determined steps. Each of the twelve steps aimed at helping students utilise certain techniques to enhance creativity, or overcome certain factors which inhibit creativity (e.g. increasing number of ideas, avoid premature close, don’t be afraid of overcoming convention practices). As a result of participating in the course, 64% of students perceived that they had developed their own creativity skills, while 36% gained confidence in their creativity skills. The course was less successful at helping students to overcome their fear or failure or judgement, with only 20% of students perceiving the course helped in this endeavour. The outcomes of these two studies demonstrate that under certain circumstances, formal courses can enhance creativity, and may sometimes help to overcome factors which inhibit creativity.

Within the field of computer science, Horton, Chelvier, Knoll, and Görs (2011) evaluated the effectiveness of engaging students in learning about ideation techniques and practically applying them to a real-world problem. During the course, participants were organised into teams. Each team was involved in identifying a real-life problem from their local community, and developing a solution to resolve the problem. Participants were engaged in learning about ideation techniques during the course, for this project. A survey of 104 participants carried out after the conclusion of the course demonstrated that students perceived the workshops on ideation provided them with skills that were important to their studies (89% of respondents), but less important for their future careers (55% of respondents).

Mathisen and Bronnick (2009) constructed a short course of five days duration for students studying social science which was aimed at enhancing participants’ (N=57) creative self-efficacy, based upon relevant social cognitive theory. The course was studied to establish whether the contents of the course were able to enhance student’s creative self-efficacy. For comparison, a course on mathematics and statistics was used as a control group. During the course participants learnt about the definition of creativity, how creativity can be influenced on an organisational and individual scale, as well as factors which can impede or improve individual and group creativity. Participants also received training in creative processes. Creative self-efficacy was measured using a pre-post-test design through a short questionnaire which participants responded to before the course had begun and after the course had completed. Outcomes of the questionnaire demonstrated that the five day course had significantly increased participants’ creative self-efficacy between the start and end of the course. Additionally, creative self-efficacy of participants in the creativity course increased, while that of participants in the mathematics (control) course remained similar, demonstrating
that it was the course content and not the educational setting itself which had increased participants’ self-efficacy.

2.8.2.3 Courses in the Domain of Engineering

Studies have also demonstrated that courses and learning activities within the field of engineering which focus on developing creativity and innovation can also be effective for enhancing related skills.

A course by Mahboub et al. (2004) orientated towards civil engineering students and focused on engineering design, investigated whether creative performance can be enhanced through a module focused on creativity. Participants (N=50) were allocated to either a control group or treatment group. Baseline creativity was established by all students undertaking the Torrence Test of Creative Thinking (TTCT) (Torrance, 1966). During the creativity module, students were engaged in “standard creative-thinking enhancement techniques such as brainstorming, attribute listing, morphological synthesis and creative dramatic that have been adapted by the project researchers”. The module included discussion on a range of creativity enhancement tools and involved participants in creativity-related exercises. After the creativity training was completed, participants’ creativity was again established using the TTCT. Analysis demonstrated that on four dimensions of divergent thinking covered by the TTCT (fluency, completeness, originality, and elaboration), the module lead to a significant increase in the fluency and originality scores of participants between the start and end of the module, while completeness and elaboration increased to a non-significant extent. Overall, it was established that the creativity of participants had increased due to participation in the module.

2.8.2.4 Courses in the Domain of Engineering, specifically focused on TRIZ

TRIZ (Russian: Teoriya Resheniya Izobretatelskikh Zadach, English: Theory of Inventive Problem Solving) is a name for a series of related heuristics and tools used for problem structuring and framing, and idea generation. TRIZ was developed in Russia in the 1940’s and 1950’s, through analysis of thousands of patents which highlighted trends over time in the development of systems of a technical nature (Altshuller, 1984). TRIZ was formally introduced in 1956 in a pioneering article by Genrich Altshuller and Rafael Shapiro (Altshuller & Shapiro, 1956). Since the 1990’s TRIZ has been widely adopted by many companies worldwide (including many Fortune 500 companies) in countries including Japan, Korea, USA, and western Europe (Savransky, 2000).

Within the field of engineering, several studies have demonstrated that courses which cover TRIZ material can lead to increased creativity-related skills and confidence in participants (Becattini & Cascini, 2016; Belski, Baglin, & Harlim, 2013; Chang, Chien, Yu, Chu, & Chen, 2016). Becattini and Cascini (2016) engaged thirty postgraduate engineering students who were enrolled in a course called Methods and Tools for Systematic Innovation, to see whether participation in the course lead to a change in students’ self-efficacy. Factors related to problem solving and creativity, including students’ self-efficacy, were using pre-post-test design, through an extended version of the questionnaire used by Steiner et al. (2011). Taken as a whole, it was found that students’ self-efficacy had significantly improved, while their self-perception of their own skills also improved as a result of the course.
Chang et al. (2016) investigated the influence of a six-week course which focused on TRIZ concepts (40 innovative principles) on the creativity of 121 first-year engineering students, through a pre-post-test design. Pre-test was established through analysis of students’ previous designs of a wind-powered toy and associated learning record (i.e. logbook) and grades they had received for a previous project. Students were allocated to either a control group, or experimental group. As part of the course, students were required to design a solar car product, keeping a learning record as they progressed. Participants of the experimental group received instruction in the use of the 40 innovative principles TRIZ technique, and utilised it design of their product. The study investigated how students performed during different states of the creative process (identify problems, analyse problems, propose strategies, select strategy, execute strategy) and to what extent the products they produced, were creative. After analysing the learning record and solar model products car made for this course, it was determined that introduction of the TRIZ technique had increased students’ several effectiveness during the overall creative process in all-sub aspects (except identifying problems) (Chang et al., 2016). Introduction of the TRIZ technique also lead to an increase of the creativity of the products which were devised (Chang et al., 2016).

A further study I. Belski et al. (2013) evaluated the influence of a TRIZ course on the problem solving performance self-perceptions and self-efficacy of participates, compared to the overall completion of a four-year engineering degree, and participation in all other engineering related course within the host institution. The twelve week course focused on teaching TRIZ concepts including 40 innovative principles, situation analysis, substance-field analysis, and method of the ideal result. In order to compare the effectiveness of the TRIZ course to other engineering courses in the institution, the Course Evaluation Survey (competed by students towards the end of each semester) results of the TRIZ course and 223 other engineering courses were analysed. Results showed that the TRIZ course was clearly rated by students as being more helpful than any other engineering course for contributing to their confidence to tackle unfamiliar problems. Additionally, the responses of freshman and graduating students to the questions “I am very good at problem solving” (i.e. self-perception of performance) and “I am certain that I am able to resolve any problem I will face” (i.e. self-efficacy) were compared to responses of those who had taken the TRIZ course. Responses of freshman and graduating students were analysed to see how engineering students’ attitudes changed over the course of completing a four-year degree. In the TRIZ course, the questions were asked at the start and end of the course to see how the course influenced responses to these questions. It was found that completion of the TRIZ course influenced participants’ responses in a more positive manner than completion of a four-year degree did. Likewise, participants of the TRIZ course responded much more positively than students from 233 other engineering courses. This suggested that the TRIZ course was more effective than the overall four-year degree, and all other engineering courses, at enhancing students’ self-perceptions of their own abilities.

The outcomes of these studies demonstrate that courses which focus on creativity and innovation are able to enhance the creativity performance and self-efficacy of students.
Specifically within the field of engineering, it is apparent that teaching TRIZ related concepts is likely to positively influence students’ creativity skills.

### 2.8.3 Meta-Analyses on Creativity Training

Several meta-reviews have also concluded that creativity training is generally an effective means to enhance the creativity of participants.

In 2004, Scott, Leritz, and Mumford (2004) published a meta-analysis of seventy studies on creativity training which had been conducted in the previous half-century. As part of the review, the seventy studies were analysed to establish whether the creativity training was associated with divergent thinking problem solving, performance, or attitudes. Of the seventy studies, 37 investigated divergent thinking, 28 investigated problem solving, while 16 investigated performance and attitudes, respectively. It was found that creativity training was found to be a strong influence on divergent thinking and problem solving. Examining how creativity training influences the different dimensions of divergent thinking (see section 2.3.1), analysis demonstrated that creativity training was associated with medium effect sizes for fluency (Δ=0.67), flexibility (Δ=0.75), originality (Δ=0.81), but was less effective at enhancing elaboration (Δ=0.54) (Scott et al., 2004). This demonstrated that creativity training is generally effective across the four dimensions of divergent thinking. Scott et al. (2004) concluded that overall, creativity training was usually an effective way to enhance the creativity of people.

In 2013, Tsai (2013) published a literature review specifically focused on the effectiveness of creativity training on adults, stating that numerous studies had investigated the influence of training on children, but not adults. The results of eleven studies published between 1987 and 2009 were analysed. The studies analysed the influence of creativity training on a variety of outcomes including specific dimensions of divergent thinking (fluency, flexibility), the novelty of solutions, the value of solutions, and the Torrence Test of Creative Thinking aptitude test. Of the eleven studies which were analysed, seven displayed medium to large effect sizes, three demonstrated small effect sizes, while only one displayed no influence of creativity training on outcomes. Like Scott et al. (2004), Tsai (2013) also considered how creativity how creativity training influenced the different dimensions of divergent thinking. Analysis showed that creativity training significantly enhanced fluency (Δ=1.29), flexibility (Δ=1.43), and originality (Δ=0.95) across the studies. Only elaboration (Δ=0.03) was found to effectively remain unchanged due to creativity training.

In follow up to the meta-analysis conducted by Scott et al. (2004), a recent review by Valgeirsdottir and Onarheim (2017) evaluated the effectiveness of creativity training based upon twenty-two studies published between 2004 and 2017. Unlike Scott et al. (2004) who only evaluated studies which "expressly focus on creativity training", Valgeirsdottir and Onarheim (2017) conducted a review based upon a more inclusive definition of creativity training, adopting the following definition: “A creativity training program is a pre-defined and structured program consisting of one or multiple sessions, with the main purpose of increasing the creativity of one or multiple participants”. Due to the varied nature of the study types and differences in methodological processes, it was reported that it was difficult to establish
statistical conclusions (Valgeirsdottir & Onarheim, 2017). However, analysis of the summarises of the twenty-two studies presented in Table 4 of the study by Valgeirsdottir and Onarheim (2017) shows that every study reported positive effects of the influence of creativity training on performance, or factors related to creative performance.

Considered as a whole, the results of the extensive meta-analysis by Scott et al. (2004), the meta-analysis by Tsai (2013), and literature review by Valgeirsdottir and Onarheim (2017), provide very strong evidence that creativity training is generally effective. However, as Scott et al. (2004) point out, there are numerous contextual factors which can influence the effectiveness of creativity training. It is not sufficient to expect that any creativity training (based upon the definition of Valgeirsdottir and Onarheim (2017)) will always be effective. Educators need to test, reflect upon and evaluate any creativity training they carry out, in order to ensure that it is indeed effective.

2.8.4 Measureable Longitudinal effects of Creativity Training

There is a limitation to many of the existing studies which have investigated the effectiveness of creativity training. The vast majority of these studies are limited to measuring the creativity performance of training participants very soon after completing the creativity training. An example of this is the recent study by Morin, Robert, and Gabora (2018), who used a pre-post-test design to measure participants change in creativity as a result of a course on creativity. Participants demonstrated an increase in creativity skills, but the post-test results were collected towards the end of the course. Although the findings of the study are important and encouraging, there was no time between the end of the course and when the post-test results were gathered, meaning the measurements did not investigate the longitudinal effects of the creativity course.

This is an issue as although creativity training may have observable immediate benefits, the long-term benefits of creativity training may be unclear. In a recently published study Meinel, Wagner, Baccarella, and Voigt (2018) reflect upon the low number of studies which had investigated the long-term effects of creativity training, stating that:

“To be considered successful, creativity trainings need to generate sustainable and long-lasting effects that should persist beyond the period of the actual training. However, most of the studies investigating creativity trainings are limited to pre- and post-training comparisons of creative performance with two measurement waves. Only few studies exist that investigate the consistency of creativity training effects so far, and the question whether creativity training effects are long-lasting has not yet been resolved.”

If engineering educators wish to adopt creativity training activities into curricula, it is imperative that the training activities are actually useful for students and lead to measurable long-term benefits.

Reflecting upon the points raised by Meinel et al. (2018), there are a limited number of studies which have investigated the long-term influences of creativity training. A summary of these studies are presented in Table 2. The study by Birdi, Leach, and
Magadley (2012) focuses on engineering participants and training in the use of TRIZ tools, so is particularly important in the context of the above mentioned studies covered in this Chapter.

**Table 2: Summary of studies investigating the long-term influence of creativity training**

<table>
<thead>
<tr>
<th>Study</th>
<th>Participants</th>
<th>Duration of Creativity Training</th>
<th>Time When Creative-Related Metrics Measured</th>
<th>Primary Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basadur, Graen, and Green (1982)</td>
<td>45 engineering professionals who heavily utilise creativity. Experimental, placebo and untreated groups.</td>
<td>Two days.</td>
<td>Two weeks after conclusion of creativity training.</td>
<td>Trained participants showed improved problem finding performance.</td>
</tr>
<tr>
<td>Basadur, Graen, and Scandura (1986)</td>
<td>112 manufacturing engineers. Trained and control group.</td>
<td>Twenty four hours over three days.</td>
<td>Five weeks after conclusion of creativity training,</td>
<td>Trained participants showed improved attitudes towards divergent thinking and had less tendency to make premature critical evaluations.</td>
</tr>
<tr>
<td>Wang and Horng (2002)</td>
<td>106 people working in research and development roles. Experimental and control group.</td>
<td>Eighteen hours spread over a year.</td>
<td>Between six and eleven months after conclusion of creativity training,</td>
<td>Trained participants showed improved idea fluency and flexibility.</td>
</tr>
<tr>
<td>Birdi et al. (2012)</td>
<td>123 engineers trained in use of TRIZ tools (intervention group), compared to 96 engineers not trained in use of TRIZ tools (control group).</td>
<td>Workshop on use of TRIZ tools. Duration of workshop is not provided. Likely duration was one day.</td>
<td>Average of thirty-three months after conclusion of creativity training,</td>
<td>Workshop participants self-reported higher creative problem-skills, higher motivation to innovate, more engagement in idea generation at work, and more patent submissions than the control group. Experts rated submitted patents (N=27) of workshop participants as more original, useful and persuasive, than submitted patents (N=16) of the control group.</td>
</tr>
<tr>
<td>Meinel et al. (2018)</td>
<td>192 graduate students (range of majors) enrolled in creativity-focused elective course.</td>
<td>Eight weeks of ninety minutes lectures, followed by a one month group task.</td>
<td>Four weeks after conclusion of creativity training lectures. Creative performance measured before and after creativity training, for reference point.</td>
<td>Participants’ creative performance (measured by Abbreviated Torrence Test for Adults) increased during the training and only decreased slightly after four weeks. Creativity training did not influence participants’ creative self-efficacy.</td>
</tr>
</tbody>
</table>

Birdi et al. (2012) investigated whether participation in a creativity training workshop (duration is not provided) covering the use of TRIZ tools had any long-term influence on creativity skills and work of participants. Two hundred and forty-one engineers who had participated in the workshop (over a two year period) were sent a survey, on average thirty-three months after completing the workshop. One hundred and twenty-three of the participants responded, a response rate of fifty-one per cent. In addition, the survey was completed by ninety-six engineers who had not participated in the workshop. The survey
asked the participants to rate their creative problem-solving skills, motivation to innovate, and engagement in ideation at work, using a 5-point Likert scale. In addition, participants were asked how many patent submission they had made over the past three years. Responses of those who had participated in the workshop were then compared to those who had not participated in the workshop. Analysis showed that workshop participants reported that their creative problem-solving skills, motivation to innovate, engagement in idea generation at work, and number of patent submissions where all statistically significantly higher than the control group. This suggests that participation in the workshop lead to long-term benefits for the engineers in their workplace. In addition, experts were engaged in the study to rate the patents which had been submitted over the past three years by the workshop participants group (27 patents) and control group (16 patents). Results established that the expert raters evaluated that on average, the patent submissions of the workshop participants group as more original, useful, and persuasive, than the patent submissions of the control group. This finding suggested that involvement in the workshop had also helped participants to prepare better patent submissions.

The studies summarised in Table 2 have an important common feature that needs to be raised. The duration of creativity training in these studies happens either over the course of several days (Basadur et al., 1982; Basadur et al., 1986; Birdi et al., 2012), several months (Meinel et al., 2018) or even longer (Wang & Horng, 2002). Each of creativity training programs involves participants learning about multiple creativity techniques, and/or multiple topics related to creativity. While each study shows positive longitudinal effects of creativity training, they do not provide clear insight into whether engaging in short (less than an hour duration) standalone creativity training activities may have measurable longitudinal benefits.

In other words, it needs to be established whether it useful for a student to learn how to apply a creativity technique in a context where the training is not part of a course or workshop on creativity. If training in a creativity technique outside the context of a course or workshop on creativity leads to measurable long-term benefits to students, educators can more confidently assert that such standalone training activities are of use to students, and that making them available online may be reasonable.

2.9 Teaching Creativity – What, How, and to What Extent?

2.9.1 The Williams Model

The Williams Model is a framework which was initially developed for encouraging creative thinking amongst gifted or talented children. Reflecting upon Williams’ model, Ronksley-Pavia (2010) states that the model “provides a practical scaffolding for developing activities and questions to stimulate thinking processes”. The model is sometimes referred to as a taxonomy, although Williams (1993) disputes this label, stating the model is “morphological, not a taxonomy since none of the factors nor dimensions imply hierarchy”.

The Williams’ model focuses on the concepts of divergent thinking and creativity (Reis, 2009, p. 323), and outlines that there are eight different possible educational objectives for enhancing creativity (Reis, 2009, p. 323). The eight objectives are based upon dimensions of
student behaviour (Williams, 1993). The first four dimensions of the model describe are
cognitive (or thinking) in nature, while the remaining four dimensions are affective in nature
(Reis, 2009, p. 323; Wormeli, 2006). The model emphasis that in order to develop student’s
divergent thinking, educators need to develop specific instructional strategies (Reis, 2009, p. 323).

Dimensions of behaviours according to The Williams Model (Reis, 2009, p. 323; Williams,
1993; Wormeli, 2006):

- Fluency
- Flexibility
- Originality
- Elaboration
- Risk-Taking
- Complexity
- Curiosity
- Imagination

Fluency, Flexibility, Originality and Elaboration are factors of divergent thinking (Cramond
et al., 2005), agreeing with the statement by Reis (2009, p. 323) that the model focuses on
concepts of divergent thinking and creativity.

In order to successfully develop creativity skills, educators need to consider low-level
cognitive processes and student behaviours to understand how this can be done (and assessed). The Williams Model is useful as it provides a framework which allows educators to
establish which dimensions of student behaviour may be focused upon, in order to enhance
students’ divergent thinking and creativity skills. Therefore, learning activities may be
developed to specifically address one or several of the possible dimensions.

2.9.2 How to Increase Creativity – Perspectives of Students, Educators and Industry
In order to try and enhance the creativity skills of engineering students it is important to take
into account the perspectives of various stakeholders including engineering students,
engineering academics, and engineering industry, of how this may be done. In a study by
Adams, Kaczmarczyk, Picton, and Demian (2009), participants from each of these three
stakeholders groups (25 people in total) were interviewed. During each interview, the
participant was asked how creativity skills can be improved in undergraduate engineers.
Analysis showed that practical activities were widely considered as being important to the
development of skills in creative thinking. In the case of engineering academics, this may
make sense as some educators associate the notion of ‘creativity’ with skills that are relevant
to engineering design (Daly et al., 2014). Professional engineers noted that development of
process and thinking skills were important, but only one specifically mentioned the use of
techniques such as brainstorming.

While it is important to consider the perspectives of all stakeholders on a general level, it is
also useful to gain the perspective of professional engineers who have extensively utilised
creativity techniques in their day-to-day work. Belski, Adunka, and Mayer (2015) engaged 46
engineering experts who regularly use utilised creativity techniques in their day-to-day work, to understand their perspectives on which skills were important to their work. It was concluded that in order to be creative, a person must possess an array of general knowledge which branches outside of their primary field of knowledge. Moreover, it was reported that in order to enhance creativity, it was important to learn creativity techniques and general knowledge, as opposed to gaining further knowledge from within their domain. This provides further evidence that engaging engineering students in learning creativity techniques is likely to be valuable for enhancing their creativity skills.

2.9.3 What to Teach as part of Creativity Training?
Based upon the discussion in section 2.8, it is apparent that engaging in creativity training may be one way to enhance the creativity and divergent thinking skills of engineering students. Providing training in the use of structured processes or heuristics may help to develop these skills and help to overcome related issues which many students face, including design fixation. In turn, this may help some students to overcome the decline in creativity skills between first and fourth years of study which have been observed in some studies (Genco et al., 2012; Sola et al., 2017).

This raises questions for educators regarding what type of processes or heuristics to teach, to what level they should be taught and understood by students, and if there are specific metrics or dimensions of creativity which they wish students to focus on developing. Existing literature provides models and frameworks which are useful in ascertaining resolution to this problem, including Williams Model and Bloom’s Taxonomy.

Reflecting upon the discussion in section 2.8.2.4, due to the widespread success of TRIZ-based courses in both enhancing creative thinking and self-efficacy of students, it was decided that TRIZ-based tools would be used for conducing the experiments during the candidature. It is important to note that this does not mean that TRIZ-based tools are the only way to enhance creativity. Only the contrary, as discussed in sections 2.8, it is apparent that creativity training may take many forms. TRIZ tools were chosen as they have a clear track-record of being effective, whilst having the potential to be learnt in under an hour (see section 2.8.1).

Limiting the nominated creativity techniques to several selected TRIZ-based tools may mean that the findings of the following experiments may have limitations regarding the extent to which the findings can be generalised. In addition, while providing participants with specified creativity heuristics may help them to raise their creativity performance in certain ways, it is possible that the same heuristics may in fact restrict participants’ way of thinking to those very heuristics.

2.10 Interest in Creativity Training
Review of the existing literature demonstrates that engineering students place value upon the inclusion of creativity material in engineering education (Waller & Strong, 2017) and that engineering students consider creativity is a skill which is important for professional engineers to possess (Wickramasinghe & Perera, 2010).
Zhou (2012) investigated medialogy (a new discipline related to engineering at University of Aalborg) students’ perceptions about the integration of creativity training into problem and project-based curriculum. The creativity training covered five lectures and three workshops over a duration of five days. It was found that “some students thought the [creativity] techniques learned were useful instruments to generate new ideas, evaluate ideas and organise teamwork during the project proposal phase” (Zhou, 2012). Moreover, most students thought that creativity training was useful, necessary, and that they may benefit from it (Zhou, 2012).

However, there is a lack of studies in the literature which have specifically investigated whether engineering students consider that shorter creativity training activities of less than an hour duration are a suitable way for enhancing creativity and problem-solving skills within engineering curricula. Understanding students’ viewpoints of such activities is critical to whether they may be able to be successful integrated into curricula.

2.11 Reflection and Research Questions

The discussion in sections 2.5 and 2.7 highlight that the creativity-related skills of engineering students may not always be successfully developed over the course of studying a four-year engineering degree, while section highlights that many students may suffer from issues which impede the creativity process, such as fixation.

The discussion in section 2.6 highlights that coverage of creativity-related material is generally rare and given a low priority in engineering curricula. In addition, the discuss has highlighted that although educators and institutions may attest that a course develops creativity skills, it is not always how this is meant to occur evident when the content of the course is actually scrutinised in the context of research and theory on creativity.

The discussion in section 2.8 has demonstrated that creativity and problem-solving skills can be effectively enhanced through formal training.

The outcome of these discussions raises several questions.

First, if Australia wishes to produce engineering graduates who have high skills in creativity and innovation to meet the needs of the Australian industry and economy, we need to comprehend how well engineering curricula actually prepares engineering graduates for this role. This raises the question to what extent do Australian engineering degrees include coursework which purposefully include a general focus on creativity. Furthermore, this also raises the question whether Australian engineering degrees includes a focus on exposing students to, and providing instruction in, the use of appropriate creativity-related heuristics. Furthermore, this also raises the question to what extent do Australian and New Zealand engineering degrees include a general focus on creativity. It is likely that if tertiary courses regard creativity in a positive manner and purposefully include discussion on the topic, such moves will provide a social environment which helps students to positively show an active interest in creativity. In turn, this is likely to positively influence their attitude and motivation towards engaging in creativity-related tasks.
At this point in time, there are no existing studies which have attempted to quantify the general coverage of creativity-related material and extent of creativity training within Australia and New Zealand (or any other country) on a nation-wide level. In order to overcome this knowledge limitation, this project will aim to provide insight into this issue through the following proposed research question, and sub-question:

**RQ 1**: To what extent is creativity-related material explicitly taught or covered as a topic within engineering curricula in Australia and New Zealand?

**RQ 1.1**: To what extent are students explicitly taught, or exposed to, creativity techniques and heuristics within engineering curricula in Australia and New Zealand?

In order for educators to assert that creativity training activities are worth the time and effort of both students and educators, it needs to be shown that such activities actually have long-term benefits to the creative performance of students. At this time, there is a lack of research on whether engaging students in standalone ideation activities of less than an hour duration (as opposed to an entire course or workshop covering several days, weeks, or months) actually has any observable benefits to student creative performance. Although the aim should be to engage students in regular ideation activities and allow them to continuously build upon such skills, this may not always be possible. Therefore, in order to verify that engaging students in such standalone learning activities worthwhile, research needs to demonstrate that it leads to observable benefits. This project will investigate this issue through the following proposed research question:

**RQ 2**: How does exposing engineering students to ideation techniques which seem initially effective, actually influence their ideation performance in the medium-long term?
Chapter 3: Literature Review – Digital Technologies and Influence of Mode

It is important to highlight to the reader that the literature review was conducted using a traditional (i.e. “narrative”) style, as opposed to a systematic style.

The snowballing approach was heavily utilised during the literature review. Cited references in the bibliography of an article were regularly accessed and evaluated for their relevance to specific sub-topics, in an iterative manner.

Databases which were utilised included in construction of the literature review were primarily SCOPUS and Web of Science.

3.1 Introduction and Chapter Content

Section 3.1 will present a review of the literature which demonstrates that computers, and specifically online-based learning, are increasingly being utilised in tertiary education. Section 3.1 will also review how familiar engineering students are with utilising digital technologies for the purposes of tertiary-based learning. In order for new software tools to be introduced to tertiary engineering education, it is imperative that the tertiary education system and the students are already familiar with using computers for educational purposes. As will presented in the review, use of computers and online learning in education are increasingly being utilised in tertiary education, while engineering students are avid owners of digital technologies and highly used to using computers for study purposes.

In order to effectively evaluate how a computer-based environment may influence performance in creativity/ideation tasks, it is necessary to comprehend how computers may influence performance during other types of tasks as well. This helps to provide understanding of whether people tend to perform better or worse when using a computer in all types of tasks, or only certain types of tasks. It also helps to provide insight into whether there are characteristics amongst certain types of tasks (e.g. active and passive tasks) which share similar outcomes. A large percentage of the literature which has been published comparing the influence of computers on task performance have covered tasks including tests or assessments, reading comprehension, and creativity/ideation.

Section 3.2 will present a review of the literature which covers the influence of using a computer to complete tests or assessments, and reading comprehension tasks. As will be presented, the literature shows that there is no clear consensus regarding how using a computer may influence performance during tests or assessments. In the case of reading comprehension tasks, there is still no consensus, but there are consistent findings amongst studies that use of a computer does not increase performance over printed material.

Reflecting upon the literature which covers software that has something to do with creativity or innovation, many of the studies can be allocated into one of two types. First, there are studies which discuss theory about how software may assist people to be creative or innovative. Such studies may also introduce, describe and demonstrate new tools which may be used for this purpose. Second, there are studies which empirically evaluate how effective
certain software, or types of software, may be at enhancing the creativity or innovation of individuals or groups compared to use of an alternative method.

Section 3.3 will review the literature and discuss the first type of studies, those that primarily discuss relevant theory and frameworks regarding how software can increase creativity and innovation capabilities, and the types (i.e. classifications) of tools which may be used to do this. There are a large number of classifications which may be applied to software tools which are designed to enhance creativity or innovation capabilities. The review will evaluate the different types of software classifications, and attempt to clarify the difference and similarities between them.

Section 3.4 will present a review of studies in the literature which investigate how effective software may be at enhancing the creativity or innovation performance of individuals and groups, in a variety of contexts.

This Chapter will discuss the findings of meta-analysis and literature review studies where possible for each section, to provide a solid basis for discussion. This will then be followed in each section by in-depth analysis of studies which are relevant to each section and the points being discussed.

3.2 Digital Technology in Higher Education and Students’ Use of Digital Technologies

3.2.1 A Possibility for Computer-based Creativity Training?
The fact that creativity training is generally successful as a way to enhance the creativity skills of participants (Scott et al., 2004; Tsai, 2013) leads to the question of how such training may become more integrated into engineering curricula, in order to try and enhance the creativity of students over the period of time taken to complete a program of study. The rapid expansion of online-based learning may provide an avenue for educators to engage engineering students in learning creativity skills.

Over the proceeding decades, online based learning has increasingly been utilised by tertiary institutions and individuals as a way to engage in gaining new knowledge and learning new material. This can vary considerably in scale. For example, institutions may include e-learning (electronic learning) and ICT (information and communications technology) within a course where material is still taught in a traditional manner, meaning students learn both online and face-to-face. This is referred to as blended learning (Oliver & Trigwell, 2005). Students may engage in some courses which deliver content in face-to-face or blended mode, while they complete other courses entirely online. Some students may even complete their entire program online through services such as Open Universities Australia.

3.2.2 The Increase in Online Learning
Tertiary institutions have been aware of the need to adapt for online and computer-based learning for several decades. This is reflected in the observation that while use of computers was once rare, utilisation of technologies such as Learning Management Systems (e.g. Blackboard, Canvas), lecture recording and email are now commonplace in higher education.
University students are some of the first within a population to adopt to new technologies. For example, Jones, Johnson-Yale, Millermaier, and Perez (2009) demonstrated that university students in the United States were quicker to obtain access to the internet and utilise many digital or internet technologies, compared to the general United States population.

A study carried out in the 1990’s reviewed the utilisation of computer-based education in Australian higher education, focused on Queensland University of Technology (Cochrane, Ellis, & Johnston, 1993). A survey completed by twenty-four higher education providers demonstrated that while some institutions had a large number of students and academics using computer based education, other institutions (including RMIT) had a very low number of students and academics using computer based education (Cochrane et al., 1993, pp. 17-18). Across all institutions, engineering ranked fifth out of eleven disciplines for adoption of computer based education. Today, computer technologies are widely integrated into tertiary curricula, and many courses are even delivered completely online.

In a report which utilised data from the U.S. Department of Education, the WICHE (Western Interstate Commission for Higher Education) Cooperative for Educational Technologies summarised that 14% of students were enrolled in at least one course that was only online-based, while a further 14% of U.S. higher education students were only enrolled in courses which were delivered online, meaning that they were enrolled fully online (Poulin & Straut, 2016, p. 15). This important finding demonstrates that over one-quarter of U.S. tertiary students had taken at least one course which was completely online, and did not involve face-to-face interaction with educators. These results are similar those reported by Jones et al. (2009), who found that 27 percent of university students had taken an online-only course at some time during their program.

This raises the question as to why institutions are adopting use of technology at such as substantial rate. A report conducted by Allen and Seaman (2007) provides insight into this, based upon the feedback of tertiary providers. Allen and Seaman (2007) investigated the early growth of online learning between 2002 and 2007 in the U.S. higher education system. This was achieved through analysis of surveys completed by degree-granting institutions within the United States. In 2007, 2504 institutions completed the survey, corresponding to 56% of all degree-granting institutions within the United States. Reflecting upon the most important reason why online education was strategically important to their own institution, many institutions cited the need to increase student accessibility to their offerings, as the reason why they started to offer online courses and programs. This highlights that it is in the financial, as well as educational, interest of tertiary institutions to create online courses and material which students are able to engage with.

3.2.3 Engineering Students’ Rate of Device Ownership
An important factor which can limit the uptake and success of digital based products and digital based learning is availability and access to computers and the internet. For example, Anuradha and Usha (2006) highlights that a disadvantage of digital format books is that problems can arise with the need to assess computers or the internet. When considering the transition of a pen-and-paper task or learning activity to a computerised version, clearly it is
important to take into consideration the technological limitations that exist. This includes access and availability of products.

Several studies have investigated the extent to which engineering students own digital devices, and use various digital technologies for the purposes of study. Margaryan, Littlejohn, and Vojt (2011) compared the rate ownership rates of several types of digital device, for students enrolled in a technical program (engineering) versus a non-technical program (social work). One hundred and thirty engineering students, and thirty social work students from two British universities were involved in the study. Ownership of mobile phones was found to be nearly ubiquitous; 100% of engineering students and 97% of social work students owned mobile phones. In contrast, ownership rates of laptop and desktop computers were less frequent. Eighty percent of engineering students and 77% of social work students self-reported that they owned a personal computer. Amongst all students, increasing the use of digital technologies in settings of formal learning was found to be significantly linked to the use of technology in informal learning and recreational contexts. This suggests that using computers in formal learning context means the student is more likely to use computers in other contexts. Overall, it was concluded that engineering students make a higher use of digital technologies across a range of different contexts than social work students, including formal learning, informal learning, and socialising.

A study by Ö zalp-Yaman and Çağiltay (2010) investigated the rate of computer ownership amongst Turkish engineering students. Out of a total of 209 engineering students, it was established that 203 (97.1%) personally owned a computer (Ö zalp-Yaman & Çağiltay, 2010), while ownership rates of mobile phones was not investigated. Johri, Teo, Lo, Dufour, and Schram (2014) noted that although many studies had been published about students’ device ownership and usage behaviour, there was an apparent lack of studies focused specifically on engineering students, remarking "through the review of recent scholarly writings, it became apparent that no studies have been performed specifically on freshman engineering students". In response to this highlighted issue, Johri et al. (2014) conducted a study of 209 first year engineering students who were enrolled at an institution in the United States, through a survey. Analysis established that students used laptops and mobile phone very frequently, while 100% of the students owned a laptop computer. The rate of internet access amongst students was also investigated. 33% of participants responded that they “always” had access to the internet while 56% that they had internet access “most of the time”, a combined total of nearly 90% of the study sample. Results were also compared based upon students’ gender. It was concluded that females made higher use of laptops and mobile phones than male students. Both males and females made frequent use of the internet, although each gender participated in certain types of activity at different rates (for example, males were significantly more likely to engage in single-player or multi-player games). Johri et al. (2014) concluded that ownership and usage rates of digital technology was high amongst engineering students, and the outcomes were reflective of studies conducted on students from other disciplines of study.

Dukić and Strišković (2015) found that engineering students perceived that they highly possessed the necessary knowledge, skills, and equipment to use electronic resources.
Moreover, engineering students’ self-perceptions of these prerequisites for using electronic resources were higher than that of students from the fields of natural sciences, biotechnical sciences, social sciences and humanities. Only students from biomedicine and health responded higher than students from engineering. This suggests that engineering students both own computers, and have the required levels of skill and knowledge to effectively operate them.

Chiner and Garcia-Vera (2017) found that engineering students hold favourable views towards the use of computers as tools to assist in the learning process, and that they possess high levels of self-confidence in their skills to effectively use computers. As part of the study, students responded to survey questions asking them specific points about their attitudes towards using computers. Of the ninety-two undergraduate students who were surveyed, 82% agreed that computers helped them to organise their work, while 91% agreed that computers allowed them to work more productively. 83% of participants agreed that they did not feel apprehensive using a computer, while 85% agreed that using a computer did not scare them in any way. Meanwhile, 84% of students also agreed that they did not need assistance of people nearby when using computers, highlighting that they are able to effectively work independently using computers. Additionally, it was established that students who had higher levels of computer experience were more likely to hold positive attitudes towards the use of software applications for use in learning.

Overall, these studies demonstrate that engineering students possess high ownership of computers and mobile phones, and that they tend to have access to the internet. Moreover, a clear majority of engineering students are also confident that they own the technology needed to engage with electronic resources, and that they possess the skills and knowledge which are required to effectively utilise these technologies. In conclusion, it is apparent that

3.3 The ‘Mode-Effect’
Mode refers to the interface with which a person engages in a specific task. For example, the use of pen-and-paper is one mode, while using a computer is another. Using a telephone or speech interpreter to complete a specific task, may also be classified as modes. Mode may also sometimes referred to as medium (e.g. Mead and Drasgow (1993)), format (e.g. Eden and Eshet-Alkalai (2013)), or platform. When tasks (such as tests) which are traditionally completed using pen-and-paper are transitioned to a computerised version, differences in metrics such as performance, efficiency, or ease of use may result. The mode, or way, in which a person completes a task, can have various consequences on that persons’ performance while completing the task.

“Mode effect” has been utilised to refer to the phenomenon where a person may complete the same equivalent task twice, but the person’s performance in the task may change depending on the mode that is used (Leeson, 2006). Research has also referred to this as the “gap” that is caused in performance by use of different modes to complete the same task (Marcenaro-Gutiérrez & López-Agudo, 2016). For example, the “test-mode effect” references situations where there is an observable difference in the test-taking performance of students who take the same equivalent test, but do so using either a pen-and-paper approach or a computer-based
approach (Clariana & Wallace, 2002). “Test-administration effect” has also been used in place of “mode effect” when referring to aptitude tests (Hedl, O’Neil, & Hansen, 1971).

The International Test Commission (2006) stipulates that in order for computerised testing to be able to replace pen-and-paper testing, it is imperative that computerised testing is shown to be at least as effective as pen-and-paper testing. In other words, it is important that the change from a pen-and-paper based approach to a computerised approach does not demonstrate any negative outcomes or influences for students, and that the quality of testing is maintained. It may reasonably be argued that this stipulation should apply equally to all forms of tasks that have been computerised, and not only to academic test taking. Yet differences in performance due to mode have been noted in educational contexts for over 30 years (Bunderson, Inouye, & Olsen, 1988).

The concept of transitioning specified tasks to a computerised platform has an extensive history of research dating back to the early 1970’s. Several of the early studies that were conducted focused on whether the test administration procedure influenced participants’ results during psychological tests (Griffith & Elwood, 1969; Hedl et al., 1971; Hitti, 1971; Johnson & Mihal, 1973), and whether the psychological tests scores awarded manually by examiners were similar to those awarded by an automated computer program (Griffith & Elwood, 1969; Hedl et al., 1971; Johnson & Mihal, 1973).

In the period of time since then, a large amount of research has been published analysing how a computer approach to completing assessment tasks may influence the performance and learning outcomes of students, compared to when a traditional pen-and-paper approach is used. Several researchers have also conducted reviews or meta-analysis in order to try and establish whether there is a clear indication that either a computerised, or pen-and-paper approach is most effective in terms of demonstrated performance. Literature reviews have highlighted that there are many factors which may influence whether a pen-and-paper task and the computerised (or digitised) version of it that is produced, may actually be considered equivalent in terms of influence on overall task performance (Leeson, 2006; Millar & Schrier, 2015; Noyes & Garland, 2008). A description of factors which may influence performance in outlined in section 3.4.

Regarding the influence that mode may have on task performance, there has been research in the literature covering a wide variety of task genres. This includes assessment tasks (such as a test) performance, reading comprehension, the influence of digital format books versus traditional print book usage during a course on final exam performance, creativity or idea generation, and other tasks such as development of special recognition and games. Many of the cognitive processes that occur may change between these tasks.

3.4 What Can Cause the ‘Mode-Effect’

3.4.1 Benefits and Disadvantages of Digital Formats
Throughout the past few decades, there have been numerous studies which have highlighted that there are inherent differences between digital and print/paper-based formats. Section 3.4 will outline the findings of several literature reviews which have identified factors which
cause the mode-effect to occur. Understanding factors which may contribute to an observed mode-effect means that it is possible to try and control for them when developing or updating computer software.

A literature review of early empirical research which had investigated the influence of reading from digital formats and print formats was performed by Dillon (1992). Dillon (1992) investigated five aspects which may differ between the formats including speed, accuracy, fatigue, comprehension, and preference. Dillon (1992) states that in regards to speed, “the evidence suggests a performance deficit of between 20% and 30% when reading from screen”. Regarding accuracy, it was concluded that reading from a computer did not influence accuracy during simple tasks such as spell checking, but use of digital formats decreased performance in tasks which were more cognitively demanding. Reading from a digital format was established to not be more fatiguing than print format, although digital formats may increase fatigue during tasks which take a long time. Reading comprehension was found to overall be equivalent between the formats, and that using one format was not detrimental compared to the other. Analysis of the reviewed studies did not present a clear outcome regarding which format was preferred, and that the outcome may depend upon the context. Overall, these outcomes suggested that reading using a digital format was not inherently negative according to series of factors, aside from the fact that it takes more time to read the text.

Leeson (2006) indentified numerous mode effects which may be classified to exist between PBT and CBT. There can be differences in participant characteristics (e.g. race, gender, memory and comprehension, speed, computer familiarity, computer anxiety), the legibility of user interface for each format (e.g. font styles and size, whitespace, interline spacing, screen size and resolution, line length), and the interactivity of the user interface for each format (e.g. scrolling, number of items on the screen, whether users can go back and forward). It is important to reflect upon these reported possible mode effects because they can apply to any type of activity carried out using different formats, not just tests.

Reflecting upon the findings of Dillon (1992), Noyes and Garland (2008) investigated the equivalence of computer-based and pen-and-paper tasks through review of forty-two studies published between the years 1992-2006. The forty-two studies investigated a mix of hypothesis including how format influences test performance, comprehension and survey censorship. It was concluded by (Noyes & Garland, 2008) that it is not possible to achieve total equivalence between the formats, and that ‘equivalence’ between formats is often judged to be true based upon the consideration of too few factors or variables. It was remarked that computer-based assessment had potential benefits including the potential for tailoring content to each student, two-way interaction, standardising test environments, and improved scoring accuracy and timing. Despite the potential benefits of computer-based assessment, it was also noted that there are inherent disadvantages of using computers in assessment. Privacy is one issue; students may have increased fears about how assessment data is collected, analysed and stored. Other issues included that it is more cumbersome and time consuming to move backwards and forwards between information when using a computer compared to using paper, and that as also highlighted by (Leeson, 2006), working on a computer is more tiring
than working on paper. Students also highlight issues with the technology itself which may occur and cause inconvenience or stress during a test; there is potential for software to freeze or stop working, or for power to be lost. In either case, it is possible that the student would have to re-sit the test. However, it is important to reflect upon the context of tests and that these issues may not be equally applicable in other settings.

Millar and Schrier (2015) explored the literature to document the differences between print format books and digital format books (e.g. eBooks). Like Leeson (2006) and Noyes and Garland (2008), Millar and Schrier (2015) established that it is more difficult to read from digital screens than a print book. Other issues which may influence task performance were also identified, including that using a tablet does not necessarily allow a reader to take notes, does not allow annotation of text, and does not allow a reader to easily read multiple books at once.

Many of the advantages which digital formats can provide are due to the use of technology to make tasks easier or more efficient. For example, digital formats have advantages over print formats including that information can be found and gathered more easily (Anuradha & Usha, 2006; Dillon, 1992; Dukić & Strišković, 2015; Stoop, Kreutzer, & G. Kircz, 2013) (such as using search functionality), navigation is easier (Dillon, 1992; Stoop et al., 2013) (such as accessing a specific page) and communication functionalities (Stoop et al., 2013). Digital formats also allow many documents to be portably carried at the same time with ease (Anuradha & Usha, 2006; Rowlands, Nicholas, Jamali, & Huntington, 2007; Subba Rao, 2001), are more easily accessible at any time (Rowlands et al., 2007; Woody, Daniel, & Baker, 2010), and have lower cost (Dukić & Strišković, 2015).

However, along with many of the efficient advantages that are brought about by use of digital format, there are also disadvantages. One of the primary issues with using digital formats over print format is that using digital formats introduce numerous ergonomic and psychological problems. As previously noted, Dillon (1992) found that reading on a computer required more time to read the same passage of text, than completing the task using a printed book. This, in part, may be attributed to the issues regarding how use of a computer can degrade important ergonomic factors. Under certain contexts use of digital factors can increase cognitive workload (Ricketts & Wilks, 2002; Wästlund, Reinikka, Norlander, & Archer, 2005), reduce reading speed (Connell, Bayliss, & Farmer, 2012; Dundar & Akçayır, 2012; Hou, Rashid, & Lee, 2017; Kerr & Symons, 2006; Solak, 2014), reduce concentration (Baron, Calixte, & Havewala, 2016), increase anxiety (Boo & Vispoel, 2012; Sulistyaningsih & Sugiman, 2016; Washburn, Herman, & Stewart, 2017) and decrease immersion (Hou et al., 2017). It is important to note however, there are cases where these findings may not apply. For example, Hermena et al. (2017) found that it was no faster to read text using print format than digital format on a tablet. In contrast to the conclusions of Dillon (1992) that use of digital formats do not increase fatigue, studies conducted more recently show that it can be more fatiguing to use a digital format (Boo & Vispoel, 2012; Hou et al., 2017; Jawaid, Moosa, Jaleel, & Ashraf, 2014; Jeong, 2012; Lee, Ko, Shen, & Chao, 2011; Muir & Hawes, 2013).
3.4.2 Influence of Mode Familiarity and Expectations on Task Performance

It may be expected that if a person is highly familiar with completing tasks using a certain digital technology, that they would actually perform more effectively using that format. For example, if a person has more experience taking tests using a computer than with pen-and-paper, it may be expected that they may perform better using a computer. Likewise, it may be expected that if a person prefers to complete a task using a certain a certain format, that their performance will be highest in that task when using their preferred format. However, research outcomes have demonstrated that these conclusions which may seem intuitive at first, are not necessarily true.

Studies have demonstrated that the familiarity a person has with using a certain digital technology, does not necessarily correspond to how well they will perform tasks using that digital technology. For example, Jeong (2014) investigated whether secondary school students’ familiarity with information technology was related to how well they were able to adapt to the introduction of CBT. It was found that students’ familiarity with information technology and how well they did in the CBT were distinct and not related. Clariana and Wallace (2002) found that there was no correlation between participants’ computer familiarity and their test performance using computer or pen-and-paper format. A study investigating the reading comprehension of twenty-four university students who natively spoke and read Arabic, concluded that there was no evidence to suggest that participants’ previous exposure to tablets influenced their reading speed and reading comprehension (Hermen et al., 2017). Investigating the influence that prior computer familiarity had on test takers’ CBT scores, Khoshisms and Toroujeni (2017) found that there was no significant relationship between participants’ (one hundred graduate students) test performance and computer familiarity. However, other research has reached conclusions which contradict these results, and demonstrate that under other contexts there may be a link between format familiarity and task performance.

Chen, Cheng, Chang, Zheng, and Huang (2014) explored whether there was any link between the level of experience which participants (Chinese university students) had with operating tablet computers, and their comprehension when reading Chinese text from tablets, print format, and computer screen. Overall, it was concluded that there was a link between previous experience of tablet operation and reading performance. Students who had higher experience of tablet operation were more successful in comprehending the materials within the text, and were able to summarise the text more accurately and completely than those with lower experience of tablet operation. The results of these studies demonstrate that there may, or may not, be a link between the levels of experience a person has with a format and how well they may complete tasks using that format. It is apparent that any evaluation regarding possible links between previous format experience and task performance would depend on the specific context that is being considered.

Singer and Alexander (2017) presented students with a reading task and asked participants whether in their own opinion, they would perform more effectively using one mode over another. Students showed a clear preference for reading text in a digital format, and predicted that they would comprehend the material better when reading using a tablet. Contrary to
students’ predictions, the students’ performance did not reflect their expectations; students actually recalled information better when they had read the text using a print format. This outcome highlights the important point that although a person may expect they can perform a task more effectively using a certain format, empirical results show that their actual performance may not match their expectations.

### 3.4.3 Influence of ‘Learning Style’ and Mode Preference on Task Performance

Research has been conducted to investigate whether people with different ‘learning styles’ perform differently when completing the same task, using the same format. A study involving 226 first year medical and 50 first year dental students identified whether students’ learning style (‘reflector’, ‘pragmatist’, ‘theorist’, ‘activist’) influenced their performance in three types of assessment: short answer, single best answer, and a standardised clinical examination test (Wilkinson, Boohan, & Stevenson, 2014). It was identified that the learning style of students had very little, if any, influence on their performance during the three types of assessment task. One study found that the learning styles (‘accommodator’, ‘divergent’, ‘convergent’, ‘assimilator’) of one hundred and seventy first year medical students did not significantly influence their performance during a Project Based Learning (PBL) exam and traditional-style exam, although students of all learning styles preferred PBL to traditional lectures (Gurpinar, Alimoglu, Mamakli, & Aktekin, 2010). A longitudinal study of 58 nursing students assessed their learning styles (‘reflector’, ‘pragmatist’, ‘theorist’, ‘activist’) and tracked their academic performance between first and fourth year of study when completing an undergraduate degree (Fleming, Mckee, & Huntley-Moore, 2011). It was found that some students’ learning style changed between the first and fourth year of study, although the clear majority of first year (69%) and fourth year (57%) adhered to a ‘reflector’ learning style. It was concluded that there was no significant relationship between students’ assessed learning style and their academic performance. The outcomes of these studies suggest it is unlikely that it is possible to accurately predict how a person may perform in a task, simply based upon their self-assessed or assessed learning style.

Researchers have also evaluated whether the way in which people prefer to do a task actually corresponds the way which they perform most effectively in the task. For example, if a person self-identifies or is categorised as a visual learner, it may be expected that the person would learn most effectively through the use of a predominantly visual approach. Therefore proponents of learning styles may suggest that learning activities should be tailored to individual students’ learning styles so that they can learn most effectively (Pashler, McDaniel, Rohrer, & Bjork, 2008). Some researchers conclude that this is a misconception or that there are often methodological issues with the way many of these studies which support the learning styles theory are conducted, including use of tools which are not shown to be valid, or the way participants are allocated to treatment groups (Kirschner, 2017; Pashler et al., 2008).

A literature review conducted by Pashler et al. (2008) investigated the available evidence to see whether there was clear links between ‘learning styles’ and task performance. Numerous studies which were analysed in the review demonstrated that people will express a preference for how to complete a certain task if asked, but there was an overall lack of evidence to
support the learning styles theory. Reflecting upon this outcome, Pashler et al. (2008) remarks that “at present, there is no adequate evidence base to justify incorporating learning-styles assessments into general educational practice. Thus, limited education resources would better be devoted to adopting other educational practices that have a strong evidence base, of which there are an increasing number”.

More recently, Kirschner (2017) argued that there were methodological issues within numerous studies have produced outcomes supporting the learning styles theory. In contrast, Kirschner (2017) highlights that there are several studies which have been well designed which contradict the learning styles hypothesis and that there is evidence that people may do necessarily perform more effectively in a task using a method which matches their ‘learning style’ (e.g. Constantinidou and Baker (2002), Massa and Mayer (2006), Cook, Thompson, Thomas, and Thomas (2009), Rogowsky, Calhoun, and Tallal (2015)). Reflecting on these points, Kirschner (2017) asserts “that there is no real scientific basis for the proposition (actually it should be relegated to the realm of beliefs) that (1) a learner actually has a certain optimal learning style, (2) (s)he is aware of what that personal learning style is and/or there is a reliable and valid way to determine this style, and (3) optimal learning and instruction entails first determining this learning style and then aligning instruction accordingly”. Overall, it is apparent that while students may have real or perceived learning styles, it can be argued that great care needs to be taken when suggesting that certain students should complete tasks using certain methods, in order to raise performance or any other metric.

3.4.4 Influence of Gender and Mode Task Performance

Another situation where the mode-effect may be introduced is when gender is considered. Male and female students may complete a task or test equally effectively using pen-and-paper. However, it is possible that transitioning the task or test to a computerised format can introduce a mode effect between the genders. If the performance of males and females is influenced in a similar manner by use of a computerised version (same, better, worse), this demonstrates that there is a mode-effect for the overall cohort. However, if the performance of one gender is influenced in a different way by the introduction of a computerised version compared to that of another gender, this demonstrates that the computerised version influences the performance of the genders in different ways. This situation would demonstrate that there is a mode-effect by gender.

Historically, the engineering profession in Australia has predominately been a male-dominant employment industry. Data shows that this is still the case today. Engineers Australia (2017b, p. 32) reports that in 2016, only 12.4% of the Australian employed engineering workforce was women. Of 10,642 the engineering enrolment places which were offered to prospective students by Australian tertiary institutions in 2016, only 1722 (16.2%) were accepted by women (note that 15.4% of applications were from women) (Engineers Australia, 2017a, p. 4). It is important to consider whether gender may in any way be a factor which may contribute a mode-effect, and what efforts may need to be made to address and overcome any such factor.
A meta-analysis of fifty studies published between 1997 and 2014 was conducted by in order to comprehend whether male and female’s attitudes towards technology had changed during the past 20 years, and how the attitudes of each gender compared to one another (Cai, Fan, & Du, 2017). Analysis of the studies found that men tended to possess a higher confidence towards the use of technology, although such differences were usually only demonstrated through small effect sizes between the groups. Reflecting on the results of a similar meta-analysis that was conducted in 1997 by Whitley Jr (1997), Cai et al. (2017) concluded that the attitudes of both males and females towards technology had improved between 1997 and 2017, but there was still evidence to suggest that males still held more favourable views of technology than females. It is important to stress that this outcome does not suggest there is necessarily a performance difference between males and females, rather that there is a slight difference in attitude towards technology.

Other studies have investigated whether there in an interaction between mode and gender. For instance, whether males and females may perform the same using pen-and-paper but have different performance when using a computerised version. Parshall and Kromrey (1993) conducted a study involving 1,144 participants which investigated whether various demographic variables, including gender, influenced performance when completing the Graduate Record Examinations (GRE) General Test (a standardised test used for establishing enrolment to graduate schools in the United States). The results demonstrated that there were differences in performance in some sub-sections of the test, based upon interaction of gender and mode. On the Quantitative section of the test, males and females performed similarly using pen-and-paper. However, males performed better on the computerised version than their pen-and-paper scores suggested they would, while women performed worse on the computerised version than their pen-and-paper scores suggested they would. On the Verbal section of the test, males performed worse on the computerised version than their pen-and-paper scores suggested they would. This demonstrates that mode may the influence the performance of genders differently in different contexts.

In a study which considered the influence of gender on test performance, Clariana and Wallace (2002) found that there was no interaction between participants' gender and their test performance using computer or pen-and-paper format. A study of 206 Turkish first year engineering undergraduate students investigated whether there was an interaction between gender and interaction mode used to complete a test (CBT or PBT), concluding that females performed slightly higher, but the difference was statistically insignificant (Özalp-Yaman & Çağiltay, 2010).

Considering findings on a wider scale, a literature review of the mode-effect conducted by Leeson (2006) found that females tended to demonstrate slightly lower performance when taking computerised tests compared to that of males, when their pen-and-paper performance tended to be the same. In contrast to the findings of Leeson (2006), a study of eighty English as a Foreign Language university students by Jalali, Zeinali, and Nobakht (2014) found that female students performed significantly more effectively than male students in a test, regardless of whether they used a pen-and-paper or computer format. However, this may suggest that there was a difference based upon gender in general, as opposed to mode.
The Programme for International Student Assessment (PISA) is an international survey conducted in over 70 countries every three years by the Organisation for Economic Co-operation Development (OECD). PISA aims to evaluate how well high school students (age 15) from various countries perform compared to one another in a range of topics including science, reading, and collaborative problems-solving (OECD, 2018). In 2015, the OECD investigated the possibility of adapting the test which had traditionally been completed using pen-and-paper, to a computerised version. In order to do this, research was conducted to evaluate if students’ performance was equivalent between modes and whether a range of factors, including gender, influenced performance on a computerised version (OECD, 2016). Forty-two countries which conducted field studies which involved students using both paper and computer. Analysis found that there was virtually no mode-by-gender interactions, suggesting that there was no appreciable difference in performance when either male or female students completed PISA using either pen-and-paper or computer (OECD, 2016). This outcome of this large-scale study suggests that there is no appreciable difference in mode performance, dependant on gender. A recent study investigated the comparability of the pen-and-paper and computerised 2015 PISA tests specifically for the countries of Germany, Sweden and Ireland (Jerrim, Micklewright, Heine, Salzer, & McKeown, 2018). Overall, it was concluded that the mode-effect was similar for males and females, and that there was little evidence that mode had a negative influence on the performance of students of either gender (Jerrim et al., 2018).

Overall, the above mentioned studies do not provide a clear indication as to whether there may be a mode-effect when people are categorised by gender. While Cai et al. (2017) found that males tend to have more favourable attitudes towards technology than females and Leeson (2006) concluded that males tended to perform slightly higher than females in CBT, there are various studies which contradict these results. This highlights that while educators need to be aware of the possibility that computerising certain pen-and-paper tasks may influence the performance of males and females differently, it is not possible to state this with certainty. It is clear that it depends on the specific circumstances and context under which the transition takes place.

3.5 Influence of Mode on Task Performance (Non-Creativity Related)

3.5.1 Influence of Mode on Tests and Assessment Performance

It has been asserted by Clariana and Wallace (2002) that there is “mounting empirical evidence that identical paper-based and computer-based tests will not obtain the same results”. Several researchers have reviewed the literature which has compared whether usage of paper-based and computer-based approaches leads to equivalent scores on assessment tasks, and reached conclusions which support this assertion. In each case, it has been concluded that there is no clear outcome as to whether a pen-and-paper or computer-based approach may lead to higher test scores. Literature reviews have identified that some studies conclude PBT is better than CBT, while others conclude PBT is better than CBT, or PBT is equivalent to CBT.
A meta-analysis by Wang, Jiao, Young, Brooks, and Olson (2008) investigated the comparability of CBT and PBT in reading assessments, specifically for studies which focused on students between K-12 (kindergarten to year 12). In total, forty-two studies (80% involved secondary school students only) published between 1988 and 2005 were analysed. Only studies which contained a within-group sample size of 25 or more were considered; in the end, all studies contained at least 100 participants. The scores of PBT and CBT from each study were consolidated and were analysed using both fixed-effects and random-effects models. It was found that there was no statistical significance between the performance of CBT and PBT using either the fixed-effects or random-effects model. This meta-analysis provides evidence that within a secondary school context, transitioning PBT to CBT is unlikely to negatively influence students’ test performance. Such findings are also likely to be applicable to tertiary education settings.

Other studies have conducted literature reviews to evaluate the influence of digital and print formats on test performance, but have not necessarily carried out meta-analysis such as done by Wang et al. (2008). Although this does not allow an overall statistical conclusion about of students’ performance in PBT and CBT to be made, it is possible to highlight the wide array of studies which have reached different conclusions regarding whether PBT and CBT lead to different test performance. For example, a study by Nikou and Economides (2013) included a review of the comparability of Computer-Based Test and Paper-Based Test modes. 26 studies published between 1989 and 2011 were evaluated. Of the 26 studies that were considered, it was established that 8 studies found PBT scores were higher than CBT, 8 studies found that CBT scores were higher than PBT, while 10 studies found that CBT scores were equivalent to PBT.

Jeong (2014) reviewed the comparability of Computer-Based Test and Paper-Based Test scores from 55 studies which were published between the years 2000 and 2014. The review considered studies from several domains including Language arts, Mathematics, Social Studies and Science. From the 55 studies, it was identified that Paper-Based Test scores were higher than Computer-Based Test scores in 15 studies, Paper-Based Test scores were lower than Computer-Based Test scores in 9 studies, while Paper-Based Test scores were equivalent to Computer-Based Test scores in 31 studies. Moreover, findings remained conflicted when studies were considered by the domain of study. This review clearly demonstrated that there was no clear answer to the question of whether a Computer-Based approach may be helpful or detrimental to the scores which students achieve under test conditions.

A review of the literature covering CBT versus PBT is shown in Appendix B. Thirty-three studies published between 2000 and 2018 have been included covering a wide range of contexts and study disciplines (one study form 1996 was included as it focuses on engineering education context). Similar to the reviews conducted by Nikou and Economides (2013) and Jeong (2014), the review clearly demonstrates that there is no clear answer as to whether CBT is a suitable alternative mode of assessment to PBT. Of the 33 studies considered, 8 studies found PBT was more effective than CBT, 10 studies found CBT was more effective than PBT, while 14 studies found that there was no difference in performance between the modes.
Reflecting upon these literature reviews, it is clear that the question of which mode leads to higher test (or assessment) performance is highly contextual to the specific study (and thus the context of the study) being considered. There is no clear answer regarding what platform is most effective for test performance, even when the context is limited to either school students or university students, or university students from a specific discipline of study. As a result, it is apparent that if educators which to reliably replace a PBT with a CBT, it is ideal that the educator first establishes that the mode does not influence performance for that specific test. However, this can be difficult for educators to achieve due to lack of available time and resources.

### 3.5.1.1 Influence of Mode on Tests and Assessment Performance (Engineering Students)

There are a limited number of studies which have attempted to identify whether there is a difference in performance when completing a test using pen-and-paper or a computer-based mode, in an engineering education context. Commenting in 2010 on the inconclusive findings of previous studies comparing CBT and PBT, Özalp-Yaman and Çağiltay (2010) asserted that “more evidences are needed especially for engineering education”.

A 1996 study investigated the equivalence of performance between first year engineering students when completing an examination using a computer-based or pen-and-paper approach (Lloyd, Martin, & McCaffery, 1996). It was established that there was no appreciable difference in performance between the modes. Also of interest was that although there was a sizeable portion of each group (between 36% and 50% depending on the group) that thought their performance would be the same if they used either mode, 39% of those who used a pen-and-paper perceived that their performance would be diminished if they used a computer, while approximately 45% of those who used a computer perceived that their performance would increase if they used pen-and-paper instead. This suggests that as an overall cohort, the engineering students perceived that their examination performance would probably be higher if they used pen-and-paper.

A study by Özalp-Yaman and Çağiltay (2010) involved 206 Turkish first year engineering undergraduate students in completing either a CBT or PBT. It was found that CBT students (N=96) scored higher than PBT students (N=113) on an exam, but the difference in performance was not statistically significant. In addition, although Female engineering students obtained higher marks than their Male counterparts in the test, the results showed that there was no significant interaction between mode used to complete the test and gender. A further study by Cagiltay and Ozlap-Yaman (2013) considering PBT versus CBT was published, but the outcomes regarding performance were the same as the study by Özalp-Yaman and Çağiltay (2010), as the same set of data was analysed.

Ita, Kecskemety, Ashley, and Morin (2014) investigated the pen-and-paper and computer based test performance of three hundred and sixty first year engineering students in a course focused on computational tools including Microsoft Excel, MATLAB and C++ programming. The course included two mid-term exams and one end of term exam. Mid-term exams consisted of a multiple choice section (part 1) and short answer or fill in the blank (part 2). Students completed the exams using one of two methods. Half the students (version A) completed the first mid-term exam using pen-and-paper and the second mid-term exam using computer. The other half reversed this process (version B) and completed the first mid-term exam using computer and the second mid-term exam using pen-and-paper. The final exam involved completing specific questions using pen-and-paper, and other specific questions using computer. Both groups of students completed the final exam in the same way. The
computer-based and pen-and-paper performance of students was then separately compared for
the three exams. For the first mid-term exam and final exam, it was established that the mode
which was used did not influence students’ exam performance (no statistical significance
between groups). On the other hand, it was found that there was a significant difference
between groups on part 2 of the second mid-term exam (but not part 1 of the second mid-term
exam). Overall, these findings demonstrated that for most cases, the performance of computer
and pen-and-paper participants was equivalent.

3.5.1.2 How Software Can Assist in Test Taking and Educational Measurement
In addition to understanding how CBT and PBT may compare in terms of performance, it is
also important to comprehend the possible different ways in which CBT can be designed.
Digital technologies have the clear ability to incorporate features which are not possible to
achieve using print or pen-and-paper formats.

Bunderson et al. (1988) proposes that there are four different ways that a computer can assist
in educational measurement (e.g. assessing how well students score compared to others).

1. Computerised Testing
   This is the simplest form of computerised educational measurement. This type of tool
   focuses on administering conventional tests on a computer. The tool presents a
   standard series of questions in a specified order which the user can answer. The
   method of interaction is only one way; the user can only interact with the software.
   The interface is static and the tool does not adapt or change in any way to the
   depending on the current user.

2. Computer Adaptive Testing
   In this type of testing the interface is not static and there is possible two-way
   communication between the user and software. The contents of the test can be tailored
   in certain ways to the user. For example, the difficulty of questions may be different,
   or the sequence or type of questions may be different. If users continuously answer
   questions of one type of question incorrectly (e.g. geometry), the software may present
   more of these style of questions so the user can practice them. In this way, the
   software adapts to the needs of the user.

3. Continuous Measurement
   Software which engages in continuous measurement is able to document a user’s
   performance over a series of tasks during a period of time, such as a course. This
   allows the software to build a profile of how the user is progressing as a learner.

4. Intelligent Measurement
   This type of tool carries out several functions which are more advanced than the other
categories of software which allows the software to act in ‘intelligent’ ways. Software
   in this category may include features such as automatic marking, providing advice to
educators and students, and comparing or analysing of student learning profiles.

It is useful to reflect upon the four categories of CBT outlined by Bunderson et al. (1988), as
there are certain similarities that exist between the ways in which a computer can assist in
taking tests, as it can help in the creative process. Section 4.5.1 presents an outline of how
computers can assist in the creative process, based upon the work of Lubart (2005).
3.5.2 Influence of Mode on Reading Comprehension, and Text Editing

Alongside CBT, numerous studies investigating the influence of mode on reading performance and how it influences comprehension, information retention, and student learning outcomes. In studies which assess reading comprehension and retention, participants are typically required to read a passage (can be short or very long) of text using either digital format or print format (or both), and then answer questions about information contained within the text. Participants may subsequently be allocated a score dependant on how many pieces of information they correctly recall or comprehended. Comparing how well participants are able to identify information and correctly recall information using either a computer screen or print, can help to identify whether participants may make more mistakes or work less efficiently using one mode than the other. Unlike tests which are an activity which requires active involvement of the participant, reading without the need to find errors or suggest amendments is an inherently passive task.

A review of 27 studies which have investigated how mode may influence reading comprehension or recall is presented in Table 39 in Appendix C. Of the 27 studies, 11 provided evidence that it was more effective to read print material, than on a computer. These studies included participants from a wide range of age groups, including students enrolled in elementary school, high school, university. On the other hand, 16 of the 27 studies demonstrated findings that it was equally effective to read material on print as it was on a screen. The studies include participants from a wide range of age groups including adults aged 45-54, and students enrolled in kindergarten, elementary school, high school, and university. Of note is the fact that there are a lack of studies in the existing literature which provide evidence that it is more effective to read on a computer screen than using print material. Overall, the review presented in Appendix C demonstrates that there while there is no consensus as to whether it is more effective to read on print or screen, there is a clear indication that reading on a screen is likely to be more effective than reading print. The literature suggests that reading on a screen will at most be only as effective as reading print.

Reflecting upon the discussion from section 3.4.1, there are several possible reasons why it may be less effective to read on a screen than using print material. The issue regarding how quickly a person is able to read has been known for decades. In a literature review of studies which analysed reading using digital format and print format, Dillon (1992) states that in regards to speed, “the evidence suggests a performance deficit of between 20% and 30% when reading from screen”. This may mean that people cannot intake as much information as quickly reading from screen as they can from print.

Contrary to reading alone, reading text and making or suggesting amendments is an active task (Eden & Eshet-Alkalai, 2013). A study carried out by Eden and Eshet-Alkalai (2013) investigated the text editing performance of 93 university student participants using both digital and print-based formats, by engaging them in the activity of editing short papers (600 words). It was established that contrary to common outcomes which are reported in many studies which compare reading performance using digital or print formats, participants performed equally effectively using either format. While studies report that reading on a computer screen is slower than on print (e.g. Dillon (1992)), Eden and Eshet-Alkalai (2013)
found that participants completed the task faster using a digital format than using print format. Additionally, it was found that text editing performance was consistent across gender.

3.5.3 Influence of Mode on Other Types of Tasks (Non-Creativity Related)

A meta-analysis conducted by Mead and Drasgow (1993) investigated the equivalence of timed and speeded pen-and-paper and computerised cognitive ability tests. 159 correlations from a total of 28 studies published between 1977 and 1992 were evaluated. It was concluded that there was a difference between modes for tests which evaluated how many limited-option questions a person could correctly answer in a specified period of time (speed test). However, no difference was identified between modes for tests which involved resolving complex questions in a specified amount of time (power test).

Studies have also considered tasks such as puzzles or games. In a recent study by Robinson and Brewer (2016), sixty participants were engaged in completing the Corsi Block and Tower of Hanoi tasks using either a traditional hands-on approach or a tablet-based touch screen version. Performance (based upon the number of moves, time taken etc.) of the participants using the hands-on approach and tablet-based touch screen version were compared to establish how well participants performed using each mode. While participants completed the Tower of Hanoi task faster when using a tablet, it was concluded that the hands-on and tablet-based versions of the tasks were relatively equivalent.

A further recent study by Bailey, Neigel, Dhanani, and Sims (2017) investigated whether mode played an effect on students’ ability to perform when completing tasks on the topic of spatial cognition. In total, two hundred and forty four undergraduate participants completed two measures of special cognition (cross sectioning and spatial visualisation) using either pen-and-paper, or computerised version. Overall, it was found that there was a significant difference in performance for both measures when mode was considered. Bailey et al. (2017) concluded that the findings “illuminates the need for research to establish instead of assume equivalence across test modes”, and cautioned against “drawing conclusions about test mode effects on test performance without first establishing measurement equivalence”.

3.6 How Software Can Assist in the Creative Process

3.6.1 Introduction

Section 3.6 will present a review which establishes the classifications of software tools which exist, that may be used to (i) enhance creativity or innovation in general and (ii) enhance creativity or innovation more specifically related to the domain of engineering.

There are several ways in which a computer may be able to assist a person to be creative, depending on the type of technology being used. Lubart (2005) concludes that computers are able to help facilitate the creative process though four different approaches. Each approach involves the computer taking on one, or several possible roles. The roles outlined by Lubart (2005) show that a computer may work as a nanny, a pen-pal, a coach, or a colleague.

- Software that is designed to work as a nanny will monitor the working process and provide a framework which can support a person in the process. The software may be
able to remind the user to do certain tasks at certain times. For example, fatigue can lead to diminished performance, so the software may remind the user to take breaks. As a result, it may be considered that the software is not directly involved in the process of idea generation.

- Software designed to work as a *pen-pal* provides functionality which allows collaboration, and allows a person to exchange ideas. An example of this is Electronic Brainstorming software which allows a group of people to exchange ideas through a computer-based platform.

- Software designed to work as a *coach* can act as an “expert system, knowledgeable in creativity-relevant techniques” (Lubart, 2005). The software may provide features such as hints, tutorials, training exercises and ways to consider different points of view.

- Software designed to work as a *colleague* is expected to work alongside the user during the creativity process. Software falling within this category may make use of artificial intelligence to be able to suggest possible solution ideas or possible routes for trying to solve the problem.

Using the general categories of creativity-enhancing software outlined by Lubart (2005), it is possible to discern and understand how a software assists a person in the creativity process. When designing creativity-enhancing software, it is also a useful framework for deciding how to classify the software, depending on how exactly the developers wish the software to assist in the creative process.

Massetti (1996) proposes a theoretical model regarding the relationship between the use of creativity software and creative performance. It is proposed that creative performance is influenced by individual creative ability, creativity training, the problem being faced, and the creativity software being used. The consideration that a person’s creative ability and any creativity training they may have had will influence their creative performance, is reflective of componential theory of creativity (Amabile, 2013). The componential theory of creativity likewise contends that a person’s creative ability, and training they have received in the use of creativity heuristics, will influence creative performance (Amabile, 2013).

### 3.6.2 Classification of Software for Enhancing Creativity and Ideation

#### 3.6.2.1 Categories of Software

Software or technology systems which are specifically created for the purpose of facilitating creativity are known as Creativity Support Systems (CSS). Various definitions of CSS have been provided throughout the literature. For example, Voigt, Niehaves, and Becker (2012) state “the term CSS refers to a class of information systems encompassing diverse types of IS [information systems] that share the purpose of enhancing creativity”. Wang and Nickerson (2017) define CSS as “specialised information systems that contribute to innovation processes in companies – product design, idea generation, research and development etc”. Garfield (2008) characterizes that “creativity support systems are computer-based systems that support individual- and group-level problem solving in an effort to enhance creative outcomes”.

Although the specific definitions proposed by researchers may vary slightly, it is apparent that
an underlying requirement of a CSS is that it is a technology-based method which is designed to help a person to be more creative. This section will outline the different classifications of CSS which exist.

A CSS can be designed to be used by groups, individuals, or both (Garfield, 2008; Müller-Wienbergen, Müller, Seidel, & Becker, 2011). Group CSS are referred to as GCSS, while individual CSS are referred to as ICSS (Müller-Wienbergen et al., 2011).

While Lubart (2005) summarises how software can assist in the creative process, there are limitations to the four categories which are provided. Software which is either designed for enhancing creativity, or may simply be used for enhancing creativity, may be categorised into named groups which share similar characteristics. Aspects include (but are not limited to) whether the software are used by individuals or groups which stages of creativity process the software aims to assist, whether the software uses creative techniques, and whether the software encourages communication. A study carried out by Voigt (2013) attempted to categorise the different types of software that were available for enhancing creativity. According to Voigt (2013) there are four categories by which creativity-enhancing software can be characterised. This includes:

1. Whether the software is used by groups or individuals
2. The approach taken enhance creativity (such as use of creativity techniques or a knowledge-based system)
3. The purpose of the software (e.g. which phase of the creativity process is focused upon)
4. The type of software. (e.g. DSS, KMS; see below)

According to Voigt (2013) there are six named classifications of software which are designed for enhancing creativity:

1. Creativity Support Software (CSS)
2. Decision Support Software (DSS)
3. Knowledge Management System (KMS)
4. Computer-Mediated Communication (CMC)
5. Group Support Systems (GSS)
6. Electronic Brainstorming (EBS)

Each one of these types of software is designed to enhance the creativity of groups or individuals in different ways, as they may make use of different approaches and serve different purposes. Reflecting upon the discussion covered in section 4.2, it apparent that it is not straightforward to assess whether software does enhance creativity. Although some types of software may share certain characteristics, it is possible to independently assess how each of these types of software may influence creativity and arrive at different conclusions for each type of software.

One of the tasks that software is able to assist with is to help in the generation of ideas and knowledge for a person engaged in the decision-making process. Such systems are
collectively referred to as Decision Support Systems (DSS) (Forgionne, 2002; Rose et al., 2016). Many DSS are designed for use by people working within management roles in organisations, and although they may be utilised in idea generation, they are not necessarily designed with creativity in mind. Therefore, not all DSS should be categorised as an enhancing creativity. Indeed, Elam and Mead (1990) assert that “a traditional DSS is not an appropriate tool to use for tasks designed to employ the unique features of a creativity-enhancing DSS”.

Another widely used type of software for enhancing creativity specifically in the context of higher education is Electronic Brainstorming (EBS) (Al-Samarraie & Hurmuzan, 2018). EBS provides a way for groups to engage in brainstorming in an efficient manner using a computer-based system. Section 4.3 provides a comprehensive description of Electronic Brainstorming systems.

### 3.6.2.2 Software Tools Used in Engineering and Related Fields

Throughout the past few decades, numerous software tools aimed at helping people working within the domain of engineering and related fields have been developed.

Computer-Aided Engineering (CAE) is a term which collectively refers to the usage of software when carrying out engineering-related tasks. Such tasks may include for example, design of components or systems, simulations, analysis, and manufacturing of products. CAE software is used in many types of engineering-related tasks including, for example, shipbuilding (Saracoglu & Gozlu, 2006), circuit design (Leung, 1989), analysis of metal fatigue (Lee, Barkey, & Kang, 2011), printing 3D organ tissue (Mironov, Boland, Trusk, Forgacs, & Markwald, 2003) and aerospace design (Elkind, Card, & Hochberg, 2014, p. xv). Categories of software tools used in CAE include Computer-Aided Design (CAD) and Computer-Aided Innovation (CAI).

Computer-Aided Innovation (CAI) is a term which refers to a software-based category of information systems. According to Leon (2009), the goal of CAI is to support enterprises throughout the entire innovation process”. Such tools are specifically utilised when an organisation or individual requires innovation to take place. CAI tools may be inspired or based upon problem-solving and creativity techniques such as TRIZ, Brainstorming, Mind Mapping and Lateral Thinking (Leon, 2009). Although CAI bears similarities to CSS, it is important to differentiate the differences between them. While CSS is primarily focused on helping a person or group of people during the creative process, CAI is focused on helping an organisation during the whole innovation process. Nonetheless, it can be argued that CAI is a form of CSS, as the innovation process requires the use of creativity. This is supported by the fact that a review of Individual CSS conducted by Wang and Nickerson (2017) classified CAI as a type of CSS.

Reviewing the literature demonstrates that people working in the domain of engineering and related fields, may utilise various types of software in efforts to try and improve their creativity or innovation. These categories of software include Virtual Reality (Alvarez & Su, 2012), Knowledge Based Systems (KBS) (Chen, 1999; Gomes et al., 2006; Hori, 1997; Sugimoto, Hori, & Ohsuga, 1994) and Computer-Aided Innovation (Shai, Reich, & Rubin,
2009; Zanni-Merk, Cavallucci, & Rousselot, 2009). A common limitation of these studies is that while the studies tend to introduce a new tool and explain in comprehensive detail how the tool operates or functions to carry out its intended function, there tends to be a lack of empirical data (such as from an experiment) which demonstrates that the tool actually increases creativity or innovation performance over an alternative method. For example, studies by (Alvarez & Su, 2012), (Sugimoto et al., 1994), (Shai et al., 2009), (Hori, 1997), (Chen, 1999) and (Zanni-Merk et al., 2009) comprehensively explain the background about why the tools should be effective and describe the operation and functionality software in great detail. However, they do not provide empirical analysis of whether the tools may be suitable for encouraging effective ideation.

3.6.2.3 Creativity Support System as Defined in This Thesis

Based upon the definitions of CSS provided at the start of section 4.5.2.1, it can be reasoned that DSS, KMS, CMC, GSS and EBS may be thought of as specific types of CSS, subject the stipulation that they are being used for creativity. Moreover, a review of Individual CSS conducted by Wang and Nickerson (2017) classified CAI (along with KMS) as a type of CSS. As a result, CSS will henceforth be used in this thesis to collectively as a way to refer to all types of software used for enhancing creativity.

![Creativity Support System (CSS)](image)

*Figure 3: Categorisation of Software for Enhancing Creativity. In this thesis, CSS will refer to all software which enhances creativity.*

3.6.3 Classification of How Software Assists in the Creative Process

Recently conducted literature reviews by Gabriel, Monticolo, Camargo, and Bourgault (2016) and Wang and Nickerson (2017) provide important insights into the current state of CSS and how they actually assist during the creative process. It is important to note that neither study attempted to evaluate the effectiveness of CSS. Rather, the aim of each study was to establish how CSS are used in the creative process.

Gabriel et al. (2016) evaluated 49 studies published between the years 1999-2013. The study primarily focused on evaluating collaborative CSS (i.e. CSS used by groups), although CSS designed for use by individuals were also assessed. Of the 49 CSS that were assessed, 55% were individual use only, 35% were collaborative use, and 10% could be used by either
individuals or teams. Using a model of the creative process which consisted of three steps (problem analysis, ideation, and evaluation), it was found that the majority (57%) of CSS only covered one phase, while 31% covered two phases and 12% covered all three phases. Overall, it was found that most CSS only covered one phase of the creative process, ideation. It was established that 53% of the CSS evaluated only engaged a user in the ideation phase of the creative process.

The literature review by Wang and Nickerson (2017) focused on ICCS and evaluated 44 studies published between the years 1986-2016. Several of the findings of the study were similar to those reported by Gabriel et al. (2016). Wang and Nickerson (2017) used a four phase model of the creative process (problem finding, information finding, idea finding, and solution finding), and identified how ICCS’s were used to assist a person through the creative process. It was identified that 44% of the 44 ICCS only covered one stage of the creative process. 33% of ICCS covered 2 stages of the creative process, while 15% covered 3 stages and 8% covered all four stages. Similar to the results found by Gabriel et al. (2016), Wang and Nickerson (2017) found that ICCS tended to place focus on idea finding (ideation in the study found by Gabriel et al. (2016)). 35% of the 44 ICCS’s only covered the idea finding stage of the creative process, while another 21% covered the two stages of idea finding and solution finding. Specific to the domain of engineering, Wang and Nickerson (2017) identified nine ICSS that were used for “engineering design and innovation”. All nine ICSS used in the engineering domain included focus on at least two phases of the creative process; primarily idea finding (i.e. idea generation) and solution finding. All nine included focus on the idea finding phase.

Overall, the literature reviews by Gabriel et al. (2016) and Wang and Nickerson (2017) show that there is a clear focus on the idea generation phase within software which is designed to help in the creative process.

3.6.4 Framework for Designing Software to Assist Creativity
Reflecting upon the design of ICCS, Wang and Nickerson (2017) note that they are “typically based on one or two creativity theories while there are many theories worth consulting”. In order to try and overcome this limitation, Wang and Nickerson (2017) formed a framework for designing ICSS through consulting several appropriate theories of creativity, instead of only one. Relevant creativity theories were evaluated to establish factors that are important when designing an ICCS. Wang and Nickerson (2017) identified three primary aspects which are important to the design of ICCS.

1. **Task motivation.**
   Wang and Nickerson (2017) argue that CSS should include features to support task motivation. Decreased motivation is likely to lead to decreased creative performance (Amabile, 2013). Task motivation is highly influenced by self-efficacy, irrespective of domain (Schunk, 1995).

2. **Supporting a structured creative process.**
   As previously highlighted, CSS tend to focus on idea generation and often only consider one phase of the creative process. Wang and Nickerson (2017) contest that
ICCS should ideally cover all phases of the creative process and that the CSS should help a person with both the divergent and convergent steps of each phase, and not only focus on the divergent step. This argument is supported by Müller-Wienbergen et al. (2011), who also state that ICSS should be designed to cater for both divergent and convergent thinking in the creative process. For example, during the idea finding stage a CSS should help a person to generate ideas and select the best ideas, not only to generate ideas. A person should also have control over the creative process, and should be able to move freely between stages of the creative process.


This includes the following sub-components:

a. “Provide stimuli that will be used as search cues” (Wang & Nickerson, 2017)


For example, a library or database which contains domain-relevant knowledge.

c. “Support the function of working memory” (Wang & Nickerson, 2017).

For example, by showing important information from a stage of the creative process, at successive stages. This means that the user does not need to actively remember all information from all stage of the creative process at all times.

d. Use of creativity heuristics and techniques.

3.7 Influence of Software on Creativity and Ideation Task Performance

3.7.1 Introduction

During the past 40 years, there has been a sizeable amount of research published which has investigated the influence that is caused to performance when completing creativity tasks using either a computer-based or traditional way. However, there are several key limitations within the existing literature when considering influence of ICCS on individuals which is discussed below.

In order to proceeded, it is required that context about some creativity techniques are provided, as these techniques will be widely referenced throughout this section. Arguably the most well known creativity technique, Brainstorming was formulated by Osborn (1963). The technique was primarily designed for use by groups, and focused on the use four main principles. The first concept is that the group should aim to generate as many ideas as possible, the key assertion being that quantity breeds quality. Group members are also encouraged to withhold criticism of ideas during the ideation stage, and that they should be willing to suggest ideas which may seem to be ‘wild’, unrealistic, or unreasonable. Lastly, groups are encouraged to combine several ideas together to arrive at new solutions.

Although early research demonstrated the Brainstorming technique is effective compared to when no structured technique is used during the idea generation stage (Meadow, Parnes, & Reese, 1959; Parnes & Meadow, 1959), research has since shown that there are limitations to the technique. For example, it has been identified that it is more effective for brainstorming to
be conducted by individuals, than groups (Diehl & Stroebe, 1991). Group settings introduce the ‘blocking effect’. As traditional brainstorming is verbal (oral communication), only one person in the group is able to talk at a time. This leads to the situation where the rate at which ideas can be generated is limited, and while group members may think of ideas while others are speaking, they may forget the idea by the time it comes to their turn to speak. This effect causes productivity loss (Diehl & Stroebe, 1991). Traditional brainstorming is generally carried out in one of two ways. Verbal Brainstorming (VBS) refers to the traditional setting described by Osborn (1963), where a group works collectively to generate ideas. This is the setting heavily influenced by the ‘blocking effect’. Nominal Brainstorming (NBS), also called Nominal Group Technique, is a variation of brainstorming which aims to overcome the ‘blocking effect’. NBS dictates that instead of working collectively in a group during idea generation, team members work individually in silence to generate ideas, then pool their ideas afterwards (hence, a ‘nominal’ group) (Boddy, 2012). VBS and NBS will be referred to as ‘traditional’ brainstorming techniques throughout this section. During Electronic Brainstorming (EBS), a team will utilise a computer-based platform in order to generate and share ideas. Therefore, use of EBS can allow a group members to write ideas into a collective space (such as a web page everyone that can write onto) and view others’ ideas that have been generated (and thus build upon those ideas) without experiencing the ‘blocking effect’. As will be discussed below, this allows EBS groups to be more effective that groups which use traditional brainstorming techniques.

3.7.2 Influence of Software on Group Creativity and Ideation

Many of the studies which compare the effectiveness of CSS and traditional approaches have limitations. Many of the published studies that have compared the influence of mode in creativity and ideation tasks have focused on group settings, rather than individuals. Most of these studies focus on comparing groups using either (i) EBS and a traditional brainstorming technique (VBS or NBS), or (ii) a Decision Support System (DSS) compared to some other form of software, or no software. Although this study aims to focus on the mode effect at an individual level, it is important to also review and reflect upon the literature which covers group settings in creativity and ideation tasks.

Table 40 in Appendix D presents a review of studies which have compared the effectiveness of groups using electronic-based, and traditional-based methods to complete an ideation or creativity-related task. As can be observed, while there is no universal agreement between studies as to which platform is more effective, it is clear that most studies conclude that it is more effective, or equally effective, for groups to complete an ideation task using an electronic-based approach.

Several studies exhibit outcomes demonstrating that groups were more effective when they utilise EBS, instead of traditional brainstorming techniques (Dennis & Valacich, 1994; DeRosa, Smith, & Hantula, 2007; Lynch, Murthy, & Engle, 2009; Michinov, 2012; Petrovic & Krickl, 1994; Pinsonneault, Barki, Gallupe, & Hoppen, 1999). However, research has demonstrated that EBS groups which are small in size tend to perform similar to groups using NBS or VBS, and that benefits to EBS are only demonstrated when the group is larger in size (Barki & Pinsonneault, 2001; Dennis & Valacich, 1993; Dennis & Williams, 2005; Gallupe et
al., 1992). A meta-analysis conducted by Dennis and Williams (2005) investigated the effects of group size in EBS. It was concluded that EBS is generally more effective when conducted in larger groups. EBS groups generally outperform VBS groups, and that outcomes comparing EBS and VBS have mixed results. A further meta-analysis conducted by DeRosa et al. (2007) investigated whether EBS groups were more effective versus traditional face-to-face (FTF) interacting groups. It was found that overall, EBS were generally more effective than traditional face-to-face interacting groups.

A notable exception to the outcomes discussed in this paragraph is the study by Kohn, Paulus, and Choi (2011), who found that groups who engaged EBS, were less effective than groups who engaged in NBS. Further studies demonstrating traditional brainstorming techniques as being more effective than EBS appear to be absent from the available literature.

In the context of brainstorming groups, it is also important to acknowledge that the ‘mode effect’ can arguably only be reliably established by studies which compare the performance of VBS and EBS groups. VBS and EBS use the same underlying process, whereby members generate ideas collectively and may use build upon the ideas of other group members. Although EBS and NBS may complete the same task, they work in fundamentally different ways: one is a collective (i.e. group) task, while the other is a task carried out individually by members of a group.

Other studies have compared the effectiveness of groups using a DSS to some other form of software, or no software. For example, Kerr and Murthy (2004) compared the effectiveness of computer-mediated (using a DSS) and face-to-face groups during idea generation, focusing how computer-mediation may influence participants’ performance on tasks which required both divergent and convergent thinking throughout the process. It was found that groups using the DSS outperformed face-to-face groups during divergent thinking aspects of the tasks, but face-to-face groups outperformed groups using the DSS during convergent thinking aspects of the tasks. Forgionne and Newman (2007) compared the effectiveness of three groups during an idea generation experiment. One group were provided no software or guidance, another group were provided with a ‘basic’ DSS which contained limited features, while the third group used an ‘enhanced’ DSS which contained an increased number of features. It was found that the group which used an ‘enhanced’ DSS outperformed the other two groups, and groups using the ‘basic’ DSS outperformed the group which were provided with no software or guidance.

### 3.7.3 Influence of Software on Individual Creativity and Ideation

#### 3.7.3.1 Introduction

A considerable portion of the early literature analysing electronic tools designed for enhancing creativity, were focused solely on group settings rather than individual settings. Reflecting upon this phenomenon, MacCrimmon and Wagner (1994) remarked:

“*Idea generation techniques for the individual have never been a central component of GDSS [Group Decision Support Systems]. Idea Generation has been seen as a group task. Thus, techniques have been designed to facilitate the sharing of ideas and*
Chapter 3: Literature Review – Digital Technologies and Influence of Mode


refinement of ideas generated by other individuals, rather than techniques which helped the individual problem solver come up with more or better ideas"

Reflecting upon the literature reviews by Gabriel et al. (2016) and Wang and Nickerson (2017), it is apparent that since 1994 attitudes towards ICSS have changed and there are now dozens of CSS which have been designed for individual use. However, it is important to note that few of the studies which have investigated (various aspects of) ICSS have considered how use of an ICCS may influence creative performance compared to when a comparable non-technology based approach is used. Studies in this area have primarily compared the use of an ICCS to individuals using a control group situation, where no external guidance or tools for encouraging the creative process, are provided.

A limitation of these studies is that it is difficult to establish whether the mode-effect can be observed, as the group using ICSS is effectively solving a different problem to individuals who are part of a control group situation. Individuals who solve a presented problem using the ICSS are may be provided with guidance or hints, while individuals who solve the same problem but do not use the ICCS only able to make use of their existing skills and knowledge. Although these studies may not be able to establish whether there is a mode-effect in the context on individual idea generation, it is important to review these studies as they provides insight into whether ICSS may enhance creative performance or not. If ICSS do not enhance creative or ideation output over a control situation (let alone a situation where individuals of each group are provided similar guidance) it is difficult to justify that use of such technology is useful. This section will review the outcomes studies which investigated the effectiveness of ICSS at enhancing creativity, highlighting that while some software may enhance creativity, while other software may not.

3.7.3.2 Influence of Software versus No Software or Control Software

A study conducted by Elam and Mead (1990) investigated whether there was any difference in the decision-making process of individuals using a creativity-enhanced DSS versus individuals using no software. When using the DSS “the user is given an explicit process model for making decisions” (Elam & Mead, 1990). Participants of the study were twelve professionals recruited from large accounting firms. In the experiment, participants were engaged in generating solutions for problems related to either a business application or public policy. Participants were not provided with any guidance or suggested process or technique to use when resolving the problems. Performance was evaluated by expert judges highly experienced in the areas of business applications or public policy respectively, using the Consensual Assessment Technique (Amabile, 1982). It was established that individuals using the creativity-enhancing DSS had a different decision-making process and were rated as having a performance which was significantly more creative than individuals who used no software.

A follow up study attempted to investigate whether individual creativity was enhanced in a decision-making environment due to the use of appropriate software, process training, or both (Marakas & Elam, 1997). Participants were a mix of forty professionals and senior/graduate students from the field of business Management Information Systems (MIS). Participants
were allocated into one of four groups for the experiment; control treatment, software treatment (a ‘creativity-enhancing’ DSS), process training treatment, or software (same DSS) and process training treatment. Process training involved learning the 5 stages that a user would follow when using the DSS (Describe problem and gather facts, assess relevancy of facts, develop explanation, test explanation, identify solutions). A modified version of the business-related tasks from Elam and Mead (1990) was presented, and members of each treatment group were asked to generate ideas. Marakas and Elam (1997) note that creativity was not discussed before or during the task, to prevent participants from purposefully trying to be creative. Performance was evaluated by expert judges using the Consensual Assessment Technique (Amabile, 1982). There were several key findings to the study. First, it was established that providing individuals with either appropriate software or process training enhanced performance over providing no software and process. Furthermore, providing an individual with both software and process training was more effective than only providing software. This outcome is to be expected; asking users to utilise software they are unfamiliar with is likely to lead to lower efficiency or performance than if they are familiar with the software. Overall, this study highlights the importance of providing users with training, or less ideally, at least ensuring that the software is sufficiently self-explanatory and intuitive.

An experimental study involving forty-four Masters of Business Administration students investigated the influence of CSS on individual creative performance (Massetti, 1996). Participants were allocated to either a control treatment, conventional software support treatment (graphics editing software), ICSS with generative focus (focused on divergent thinking), or ICSS with exploratory focus (focused on refining and elaborating on ideas). In order that the participants’ knowledge about creativity was consistent across the groups, participants of the study were first provided with a one hour lecture. The lecture covered topics including the importance of creativity in business decision-making, a description of the creative process, and suggested ways for overcoming obstacles when creativity is required. Individuals using each DSS treatment were then provided with instruction about certain features of the appropriate DSS. All subjects were instructed to generate as many ideas as possible to a provided problem during 30 minutes. Creativity was evaluated by judges who had high levels of experience in the related field. It was found on average, use of either ICSS improved the total number of ideas and number of creative ideas over the control treatment group, but not over the conventional software support treatment group (Massetti, 1996). This suggests that use of software helped the creative process, but that software specifically focused on enhancing creativity was no more effective than conventional support software. This outcome clearly highlights that it is not sufficient to expect that just because software is designed with enhancing creativity in mind, that the software will be successful in this endeavour.

Research has demonstrated that software which is designed to assist users to be creative, will not always be successful in this objective (Durand & VanHuss, 1992). In the study, eighty-eight Masters of Business Administration students completed two tasks which required idea generation, one using no software, and the other using software. After each task, participants submitted a written case analysis. It was found that when software was used during idea
generation stage, the quantity of ideas, originality of ideas, and detail of ideas did not significantly change. However, it was established that overall creativity decreased when software was used during idea generation. This finding highlights that certain software can actually have a detrimental influence on creative performance, even though it is designed to enhance creativity.

Another study investigated the performance of individuals who used a DSS versus individuals who used control software (a word processor), although the study did not include individuals who used a non-software based approach for comparison (MacCrimmon & Wagner, 1994). It was found that use of the DSS increased performance, relative to the individuals who made use of a word processor software.

This outcome adds evidence to the notion that carrying out idea generation on a computer does not in itself increase creative output. In order for creativity to be enhanced, the software being used needs to be designed in a way to allow this to occur.

When considered as a whole, the studies highlighted throughout this section demonstrate that software which is designed to enhance creativity on an individual level can be successful in this endeavour. Some studies report findings showing that software can enhance creativity compared to a no-software control situation (Elam & Mead, 1990; Marakas & Elam, 1997; Massetti, 1996) or computer-based control situation (MacCrimmon & Wagner, 1994), while others report that use of software can actually decrease overall creativity (Durand & VanHuss, 1992). The results of Massetti (1996) demonstrate that software can enhance creativity, but that software focused on enhancing creativity in decision-making situations may not be more effective than similar software which is designed for decision-making in general. From the outcomes of Marakas and Elam (1997), it is apparent that if software is not incredibly self-explanatory and intuitive, users need to be trained in use of the software for it to be effective.

There are several important limitations to the studies reviewed in this section. First, it is important to note that participants in each case are from the field of business and utilising DSS. While DSS can be used in context which require creativity, the type of problems which they are designed to resolve relate to the field of business and not technical/physical related fields such as engineering.

### 3.8 Influence of Mode on Self-Efficacy

#### 3.8.1 Introduction

Reflecting upon the discussion of self-efficacy and its relation to creative performance and engineering problem-solving in section 2.4.4, it is apparent that there is a need to increase the self-efficacy of students where possible. Self-efficacy is a major factor which influences creative performance. It has been demonstrated that creativity training based upon concepts such as TRIZ can enhance the self-efficacy of engineering students (Becattini & Cascini, 2016; I. Belski et al., 2013). As a result, it is therefore important to also consider students' self-efficacy when any learning activity (such as creativity training) is transitioned from a pen-and-paper approach to a computerised approach.
It is therefore imperative that the transition from pen-and-paper to computerised approach does not negatively influence the immediate, or development, of self-efficacy in any way. Within the existing literature, there is a lack of studies which have considered whether there is a mode-effect in relation to self-efficacy, within the context of creativity training. There is therefore a need for research to establish whether there is an observable mode-effect in relation to self-efficacy, within the context of creativity training.

Existing literature which has investigated possible mode-effects in relation to self-efficacy, have focused on the context of students completing tests or assessment tasks. While the context is different, it is nonetheless important to reflect upon the outcomes of studies in this context to understand the existing literature.

3.8.2 Assessment Tasks and Tests
Several studies have highlighted that computer-based assessments can have positive effects on self-efficacy and motivation. One study found that participants who completed a Computer-Based Test (CBT) reported a slight increase in efficacy, while participants who utilised a Paper-Based Test (PBT) reported a statistically significant decrease in efficacy (Chua, 2012), suggesting the computer-based approach may have positively influenced students’ efficacy during the test compared to a paper-based approach, and aided in the development of higher motivation. A further study carried out by (Chua & Don, 2013) the conclusion that participants who completed a CBT experienced a considerable increase in motivation and self-efficacy during the test situation, whereas participants who completed the same test as a PBT experienced a considerable decrease in motivation and self-efficacy. These findings are built upon by (Nikou & Economides, 2016) Nikou and Economides (2016), who determined that using a computer to complete a series of self-assessment tasks lead to a positive statistically significant increase in self-efficacy and motivation, while using a pen-and-paper method resulted in no significant change to self-efficacy or motivation.

3.9 Preference of Mode for Completing Tasks
Understanding the way that people prefer to complete a task is important. Although the way in which a person prefers to complete a task does not necessarily correspond to the way in which they will actually most effectively complete the task (see section 3.4.3), it is likely that a persons’ motivation to complete a task will be higher when completing it using their preferred mode. As outlined in the Componential Theory of Creativity, motivation is critical to creative success, and mode preference is a factor which can influence motivation.

Review of the existing literature demonstrates that the mode which people prefer to use to complete a task, can depend on the nature of the task. As will be detailed in this section, the literature demonstrates that people usually prefer to complete tests on a computer, but prefer to read using print material. Currently, there is a lack of research in the literature regarding whether engineering students prefer to complete creativity training activities using computer or pen-and-paper.

However, as will be discussed, the way that a person prefers to complete a task is not always the way they will actually do it, even when provided with a choice. In addition, just because a
task may become more widely available and accessible to complete electronically, this does not mean that preference towards completing the task electronically will also increase.

3.9.1 Preference of Mode for Tests and Assessment Tasks

There is no consensus amongst studies in the literature which have investigated students’ preference of mode for completing tests and assessment tasks. However, there is a clear trend. Most of the studies in the literature demonstrate that students prefer to use a computer to complete a test, rather than pen-and-paper.

Studies which report that students prefer computer for completing tests cover both school students, and university students enrolled in a range of study disciplines from numerous countries (Al-Amri, 2007; Boo & Vispoel, 2012; Flowers, Kim, Lewis, & Davis, 2011; Hosseini, Abdin, & Baghdarnia, 2014; Jawaid et al., 2014; Karadeniz, 2009; Khoshsima, Hosseini, & Toroujeni, 2017; Khoshsima & Toroujeni, 2017; Lim, Ong, Wilder-Smith, & Seet, 2006; Sanni & Mohammad, 2015; Shonfeld & Meishar-Tal, 2018; Wibowo, Grandhi, Chugh, & Sawir, 2016). However, there are some studies which report that students prefer to complete tests using pen-and-paper.

Dammas (2016) investigated the preferences of sixty university students from Saudi Arabia who were enrolled in a course on chemistry towards completing tests using either pen-and-paper or computer. Responding to the question “I prefer CBT compared with PPT”, participants responded with a mean value on 2.53 on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). In addition, participants responded to the question “CBT is better than PPT” with a mean value on 2.26 on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). These findings demonstrated that students showed a clear preference for completing tests using pen-and-paper over computer. Despite this, students agreed with the statement that they liked computerised tests because they were able to receive their results quickly and automatically.

Washburn (2017) investigated the perceptions of one hundred and thirty-four university veterinary students towards electronic and pen-and-paper multiple-choice exams. Participants were enrolled in a semester long veterinary course which contained four twenty-five question multiple choice exams. Using a split-halves design methodology, participants each completed two of the four tests using computer, while they completed the two remaining tests using pen-and-paper. In other words, half the participants completed the paper (P) and computer (C) tests using a P–C–P–C sequence, while the other half used an C–P–C–P sequence. At the end of the semester, eighty-seven per cent of participants reported that they preferred to take the tests using pen-and-paper instead of computer. Eighty-five per cent of participants reported they experienced additional anxiety at the start of a test when it was electronic, with many citing concerns about potential technical issues with the device, battery issues, difficulties uploading or downloading the exam, and being unable to write on the exam. Eighty per cent of students felt that having to write on scratch paper instead of directly on the exam itself when using a computer impacted their ability to think through the questions.
3.9.2 Preference of Mode Reading

There is no consensus amongst studies in the literature which have investigated students’ preference of mode for reading. However, there is a clear trend. Most of the studies in the literature demonstrate that students prefer to use a reading using printed material, rather than electronic material.

Studies which report that participants prefer to read using print material over electronic material cover both school students, and university students enrolled in a range of study disciplines from numerous countries (Aharony & Bar-Ilan, 2016; Christianson & Aucoin, 2005; Croft & Davis, 2010; Fernandez, 2003; Folb, Wessel, & Czechowski, 2011; Goodwin, 2014; Jeong, 2012; Kazanci, 2015; Liu, 2012; Marques de Oliveira, 2012; Millar & Schrier, 2015; Mizrachi, 2015; Quan-Haase, Martin, & Schreurs, 2014; Roach, McEathron, Russell, Waters, & Emde, 2014; Shelburne, 2009; Singer & Alexander, 2017; Slater, 2009; Williams & Best, 2006; Woody et al., 2010). However, there are studies which contradict this finding and report that participants prefer to read electronic material.

Reflecting upon studies in the literature which report that participants prefer to read using electronic material, there is no clear trend in participant characteristics. Moravec and Pešková (2016) investigated the perceptions of two hundred and fifty Czech lower secondary school students towards electronic textbooks, while Tveit and Mangen (2014) investigated the attitudes and preferences of one hundred and forty Norwegian tenth grade students towards reading on screen and print material. Both studies found that most students preferred reading on screens over print. In contrast the issues of eye strain and reduced reading speed when reading on screen reported by several studies (see section 3.4.1), fifty-four percent of the participant in the study by Tveit and Mangen (2014) reported that reading on screen was most comfortable for their eyes, while sixty-two percent perceived that they could read faster on screen. In addition, students overall reported other benefits to reading on screen including being more relaxing, being more immersive, and making it easier to remember information Tveit and Mangen (2014).

Dukić and Strišković (2015) investigated the reading preferences of nine-hundred Croatian university students, while (Weisberg, 2011) investigated the reading preferences of university students from the United States. Both found that the majority of participants preferred to read electronic material. Responding to the question “I prefer to use electronic resources rather than printed materials”, Dukić and Strišković (2015) found that participants responded with a mean value on 3.29 on a Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). When asked whether they would use electronic textbooks for their college classes if given the choice, (Weisberg, 2011) found that fifty-four percent of participants responded positively.

3.9.3 Preference versus Actual Usage

Despite the fact that most studies in the literature report that students overall prefer to read using print material, most students actually read study material electronically. Studies investigating the borrowing habits of university students from their host institution’s library demonstrate that students borrow vastly more electronic books than print books (Bailey, 2006; Chen-Gaffey & Getsay, 2016; Fry, 2016). Even when students are provided with the
option of borrowing the same title book in either print or electronic format, numerous studies demonstrate that students will most often still borrow the electronic copy of the book (Goodwin, 2014; Kimball, Ives, & Jackson, 2009; Littman & Connaway, 2004; Morgan, 2010; Ramirez & Tabacaru, 2015; Stephens, Melgoza, & Wan, 2008; Taylor, 2013).

Reasoning for this can be found in the points raised in section 3.4.1. Electronic formats allow many documents to be portably carried at the same time with ease (Anuradha & Usha, 2006; Rowlands et al., 2007; Subba Rao, 2001; Weisberg, 2011), are more easily accessible at any time using the internet (Rowlands et al., 2007; Woody et al., 2010), make searching for information easier (Dillon, 1992; Stoop et al., 2013), and have lower cost (Dukić & Strišković, 2015). This demonstrates that despite people may prefer to complete a certain task (such as reading) using a certain mode, in reality they may often elect to use their non-preferred mode due to other benefits offered by the non-preferred mode. In the case of electronic books, the benefits of lower cost, greater accessibility, lower carrying weight, and search functionalities often outweigh the fact that a person would actually prefer to read print material.

These outcomes may suggest that even if students prefer to complete creativity training activities using pen-and-paper, they may actually make higher usage of the learning resources if they are provided electronically in a manner which allows them to be easily accessible and available at any time.

3.9.4 Longitudinal Changes in Preference over Time

One may expect that with the increasing adoption and availability of electronic books, peoples’ preference towards using electronic books over print books may also increase over time. However, research has demonstrated that this is not necessarily always the case.

In 2008, Kazanci (2015) investigated the preferences of three hundred and fourteen South African student teachers towards reading from printed paper or a digital screen. In 2014, the study was repeated involving three hundred and three student teachers from the same institution. Comparison of the 2008 and 2014 results provided a longitudinal insight into the change in students’ preferences towards reading on screens over a period six years, whilst the rate of electronic book usage was steadily increasing. In 2008, seventy-eight point five percent of students preferred to read on paper. In 2015, seventy-seven point three percent of students preferred to read on paper. This demonstrated that over the six year period, preference towards reading from screen stayed effectively the same and only increased by one and a half percent.

A study by McKiel, Dixon, and Vicna (2012) investigated the change in perceptions of university students towards reading electronically between 2008 and 2011 through comparing the results of two worldwide surveys. In 2008, the “Global Student E-book Survey” was completed by over 6600 university students from seventy-size countries. In 2011, the survey was completed by over 6300 university students from one hundred countries. Results showed that although there was clear preference for electronic books in both years, overall preference for electronic books over print books declined by three per cent between 2008 and 2011. Surprisingly, this finding demonstrated that students’ preference towards reading
electronically dropped over this time period when electronic books were becoming more widespread.

Overall, these studies demonstrate that it is not reasonable to expect that just because a task may become more readily available in a new and accessible format, this does not necessarily mean that preference (not actual usage rates) for the format will also increase.

3.10 Reflection and Research Questions

The literature review carried out throughout this Chapter has highlighted several areas which are absent from the existing literature.

As discussed in Chapter 2, there is a need to provide engineering students with enhanced opportunities to work on building their creativity skills. One potential method to achieve this was to provide opportunities to engage in creativity training activities focused on building a chosen skill; in this case, idea generation. Building upon this, Chapter 3 discussed the rapid adoption of online learning and how there may be opportunity to provide students with online creativity training activities to build their skills. However, it was identified that due to the mode-effect phenomenon, it was unclear whether engineering educators may transition creativity training activities traditionally done in a classroom setting using pen-and-paper to an online environment while ensuring that the high standard of learning outcomes were maintained.

This raised the question as to whether it may be suitable for educators to adopt creativity training activities to an online environment or not, and that empirical evidence was required.

From the literature review, it is apparent that there is a lack of studies which have attempted to establish if there is an observable mode-effect (based upon performance and/or self-efficacy) when individuals are requested to apply a specified creativity heuristic using either pen-and-paper or equivalent computer-based approach. Studies which engage participants in the same idea generation activity using the same specified creativity heuristic, using the same level of training, and using the same resources (only one is computer-based and the other pen-and-paper) are absent from the literature.

Some existing literature has focused on comparing the effectiveness of groups which does not have outcomes which are easily transferrable to individuals. Other studies have focused on comparing the use of CSS to no software, or software which is not designed for enhancing creativity.

As a result, to address this important research gap in the literature and evaluate whether online ideation-based creativity training activities were suitable from the perspective of an educator or not, the following research question was proposed:

**RQ 4**: How does mode influence ideation performance and self-efficacy during ideation-based creativity training?
Reflecting upon the discussion in section 3.9, the second major point raised throughout this Chapter is there is currently a lack of research on whether students prefer to engage in creativity training using one mode or another.

If a person is able to engage in a task using their preferred method, it is likely that this may increase their motivation to engage in the task. Therefore, if educators are able to understand which mode students prefer for creativity training activities, they may be able to enhance engagement rates with such activities by providing them in the mode that students prefer. To overcome this limitation in the literature, the additional following research question was proposed:

**RQ 5:** Which mode do engineering students prefer to use to engage in ideation-based creativity training?
Chapter 4: Review of Creativity in Australian and New Zealand Engineering Degree Programs

4.1 Introduction
Chapter 2 highlights issues with engineering curricula and the development of engineering students’ creativity skills. This raises the question of what may be done to try and enhance the way creativity is taught in engineering curricula throughout Australia.

Reflection upon the Componential Theory of Creativity provides insight into what may be effective approaches for trying to enhance the creativity and thinking skills of engineering students. According to the Componential Theory of Creativity as shown in Figure 1, attempts to improve students’ ability to generate solution ideas primarily depend upon influencing Task Motivation and Creativity-Related Processes. Engineering degrees already have a large focus on the inclusion of domain-relevant skills, so further expansion of this is not required.

Regarding the Componential Theory of Creativity, it is apparent the issue of fixation and being unable to effectively generate ideas during idea generation (discussed in section 2.7.4) primarily relates to the third stage of the creativity process outlined in the theory, response generation. In order to try and improve the creativity and thinking skills of engineering students, educators may focus on response generation. Focusing on ways of empower students to overcome the issue of fixation and enabling students to be able to more effectively generate responses to a presented problem, may be one approach to enhance the creativity and thinking skills of engineering students.

This certainly does not mean this is the only approach to enhancing creativity, but fixation is one important issue related to creativity skills which educators can actively aim to assist students to overcome.

This raises the question to what extent do Australian engineering degrees already include coursework which purposefully includes a focus on exposing students to, and providing instruction in, the use of appropriate creativity-related heuristics (i.e. creativity training).

The Componential Theory of Creativity also highlights that Task Motivation is very important to the creativity a person may demonstrate. Reflecting upon Figure 1, it is apparent that Task Motivation is heavily influenced by external factors, including the Social Environment. This raises the question to what extent do Australian engineering degrees include a general focus on creativity. It is likely that if tertiary courses regard creativity in a positive manner and purposefully include discussion on the topic, that this would provide a social environment which helps students to positively show an active interest in creativity. In turn, this is likely to positively influence their attitude and motivation towards engaging in creativity-related tasks.

At present, there is no quantifiable data regarding the coverage of creativity training within Australian and New Zealand engineering curricula on a nation-wide level (or any country, in fact). In addition, there is no quantifiable data regarding the coverage of more general
creativity-related material within Australian and New Zealand engineering curricula on a nation-wide level.

4.1.1 Existing Studies
Existing studies in the literature which have attempted to identify the coverage of creativity material have been limited to analysis of courses from one institution. A discussion of the relevant literature is discussed in section 2.6.

Existing studies which have investigated either the actual (content evaluated based upon creative theory) or perceived coverage of creativity material have covered only one institution. Studies which have investigated the actual coverage of creativity material within courses originate from Canada (Marquis et al., 2017), and the United States (Daly et al., 2014; Kazerounian & Foley, 2007), while studies which have investigated students' perception of the extent of coverage of creativity-related content originate from France (Gaudron & Kövesi, 2017), United States (Carpenter, 2016; Kazerounian & Foley, 2007) and Spain (Martin-Erro et al., 2016). In each of these studies, it was found that either the actual or perceived coverage of creativity-related material was very low. For example, (Marquis et al., 2017) found that only 1 out of 144 engineering courses from the host institution that were evaluated, explicitly included material that was related to creativity. Refer to section 2.6 for further details on each of these studies.

4.1.2 Purpose
The purpose of this survey is to:

- Quantify the explicit coverage of creativity-related material within Australian and New Zealand engineering curricula on a nation-wide level.
- Quantify the explicit coverage of ideation-based creativity training within Australian and New Zealand engineering curricula on a nation-wide level.

It is imperative to note that the aim of this survey was not to evaluate whether any given course may enhance creativity any possible number of ways. The survey specificity focused on the two points above. Courses which were not in principle aimed at developing creative skills (such as a course on Intellectual Property) would very likely be excluded. While such courses may lead to increase in creativity skills, and may be worthy of evaluation, it was outside the scope and purpose of the survey to evaluate this.

Creativity training within this Chapter will refer to the above mentioned (see section 2.8) definition given by Valgeirsdottir and Onarheim (2017): “A creativity training program is a pre-defined and structured program consisting of one or multiple sessions, with the main purpose of increasing the creativity of one or multiple participants”. Regarding the second point, the focus was specifically on ideation-based creativity training, as opposed to any form of creativity training.

Within this Chapter, “program” and “degree” will refer to the overall program of study which must be completed from commencement to graduation. A “course” (sometimes also referred to as a “unit” or “subject”) within this Chapter will refer to one of the fundamental building
blocks which form part of the overall degree program. Within Australia, students typically complete between thirty and forty courses to complete a four-year engineering degree.

4.2 Methodology

4.2.1 Scope and Practicality
Clearly, it is impractical to try and assess the coverage of creativity material within engineering curricula on a nation-wide level through discussion and consultation with all involved course co-ordinators, and in-depth analysis of all course material. This would involve a project with hundreds of engineering academics and would have unmanageable scope. As a result, this meant that the methodology required a more accessible means of obtaining required information about each course.

As discussed in section 2.6, it is important to bear in mind that previous studies have found that even though academics may consider that their course builds creativity skills or includes creativity material, students may perceive that the course does not include any material on creativity (Kazerounian & Foley, 2007), and that when the course content is evaluated according to creative theory the creativity content may actually be very limited or non-existent (Daly et al., 2014). This demonstrates that while comparing the perceptions of academics to that of students or an evaluation of the course content may provide useful insights, analysis of academics’ perceptions or assertions is unlikely to provide an accurate representation of the coverage of creativity-training and general creativity content in engineering curricula.

Due to the vast number of engineering disciplines within Australia and New Zealand, and thus the large number of programs and courses, the scope of this review was limited to the discipline of electrical engineering in Australia Due to the small number of electrical engineering programs in New Zealand (4 programs) this was expanded to also include electronic engineering programs (3 programs) in New Zealand. Electronic engineering degrees from Australia were not included.

In addition, this review was limited to the evaluation of undergraduate four-year engineering degrees. This meant that postgraduate engineering degrees were not included in the evaluation. Reflecting upon the Australian Qualification Framework this corresponds to AQF Level 8; Bachelor degree with honours year (Australian Qualifications Framework Council, 2013). Likewise, reflection upon the New Zealand Qualification Framework demonstrates that this corresponds to NZQF level 8, also Bachelor degree with honours year (New Zealand Qualifications Authority, 2016).

4.2.2 Compiling a List of Electrical Engineering Programs
In order to carry out the review it was required that a list of electrical engineering degree programs within Australia, and electrical and electronic engineering degree programs within New Zealand, was compiled. This was required so that a list of all courses within each degree program could also be compiled.
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Under the Washington Accord agreement, Engineers Australia and Engineering New Zealand are recognised by the International Engineering Alliance as the engineering accreditation bodies for Australia and New Zealand, respectively (International Engineering Alliance, 2017). As a result, a list of all four-year undergraduate electrical engineering degrees accredited by Engineers Australia, and four-year undergraduate electrical and electronic engineering degrees accredited by Engineering New Zealand was compiled.

To do this, a list of all engineering courses that were offered at an Australian tertiary institution in 2017 and were accredited by Engineers Australia, was consulted (Engineers Australia, 2017c). A spreadsheet of all four-year undergraduate degrees with the word “electrical” and “engineering” in the title, along with the applicable host institution was created. The program structures for seven programs were not available from the host institution’s website, and were excluded from further analysis. This resulted in a list of thirty-four unique degrees that were offered at twenty-five different tertiary institutions.

Likewise, a list of all engineering courses that were offered at a New Zealand tertiary institution in 2017 and were accredited by Engineering New Zealand, was consulted (Engineering New Zealand, 2018). A spreadsheet of all four-year undergraduate degrees with the word “electrical” or “electronic” and “engineering” in the title, along with the applicable host institution was created. This resulted in a list of 7 unique degrees that were offered at 7 different tertiary institutions.

A summary of the Australian and New Zealand engineering programs is available in Appendix F.

4.2.3 Compiling a List of Courses within Each Electrical Engineering Program

Following the identification of all applicable engineering programs that would be analysed, it was then required that a list of core or compulsory (further detailed in section 4.2.3.1) courses which made up the content for each degree, was created.

To compile a list of all courses which formed a part of each applicable engineering program, the website of the applicable tertiary institution which hosted each engineering program was consulted. The publicly accessible online program handbook or program structure (which provided a list of all the courses required to complete the program) of each engineering program was located on the applicable host institution’s website.

A separate spreadsheet was created for each engineering program (i.e. forty-one spreadsheets in total), and a list of all the courses which a person must complete to graduate from a specific program were recorded on the appropriate spreadsheet. This resulted in the identification and recording of a total of approximately one thousand one hundred Australian courses and two hundred and fifty New Zealand courses.

4.2.3.1 Studying Creativity: Opportunity versus Requirement

It is important to acknowledge the difference of whether engineering programs provide the opportunity for students to be engaged in creativity related material, compared to a requirement that students be engaged in creativity related material. If engineering educators
and course designers wish students to be able to effectively build upon their creativity skills, creativity material should ideally form part of the core courses of the engineering program. It is unreasonable for educators to assert that students are able to build their creativity skills, if the courses which build these skills are only offered as elective courses.

Elective courses refer to the situation whereby a student has to complete one course from a choice of several/numerous available courses. If course(s) which include creativity material are only provided as an elective(s), it would mean that a student may complete their engineering degree without studying the material, and thus complete the degree without being exposed to creativity related content. In the interest of enhancing students’ creativity skills, this is not an ideal approach to teaching creativity. Therefore, all forms of electives were removed from analysis. Only the core or compulsory courses that a student must complete were analysed.

Elimination of all elective courses resulted in the outcomes shown in Table 3. A total of nine hundred and nineteen core courses from Australia and one hundred and ninety core courses from New Zealand were included in further analysis.

Table 3: Overview of the total number of degrees and courses that were analysed

<table>
<thead>
<tr>
<th>Country</th>
<th>Host Institutions</th>
<th>Degrees Analysed</th>
<th>Courses Analysed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>25</td>
<td>34</td>
<td>919</td>
</tr>
<tr>
<td>New Zealand</td>
<td>7</td>
<td>7</td>
<td>190</td>
</tr>
</tbody>
</table>

4.2.4 Analysis of Engineering Courses

4.2.4.1 Usage of Course Outlines

The data source that was chosen for analysing the potential coverage of creativity within each course, were the publicly available course outlines hosted on each applicable host institution’s website. This includes all content in the course outline including description, learning outcomes, aims and objectives, assessment task descriptions, capability development, overview of learning activities etc.

Previous studies have analysed course outlines as a way of assessing and evaluating the coverage of certain aspects within degrees offered by tertiary institutions, demonstrating that it is an effective way of evaluating and comparing the contents of degree programs.

For example, Kouzani, Lee, and Joordens (2010) investigated and compared the program structure of twelve electrical and electric engineering programs from Australia, UK, USA and Singapore, through information “collected from the official websites of each university”. Building upon this, Kouzani, Adams, and Gibson (2016) investigated the common and different features of twelve biomedical engineering programs of universities from Australia, New Zealand, USA, Singapore and UK, through analysis of course outlines from university websites and catalogues. This allowed a comprehensive analysis of which topics were widely covered throughout the degrees, and which were not.
Memon (2007) conducted an analysis of sixteen electrical engineering degree programs from countries that are part of the Gulf Cooperation Council (Saudi Arabia, United Arab Emirates, Qatar, Kuwait, Bahrain), including the subjects studied, unit credit points and unit contact hours. Reflecting upon the methodology, Memon (2007) states that “information used in the analysis was taken from respective university websites and catalogues available in the public domain”.

Specifically related to the area of creativity, Marquis et al. (2017) investigated the coverage of creativity within several disciplines of study at a Canadian tertiary institution. This included qualitative analysis of all the publicly available course outlines of undergraduate courses offered by the institution. Disciplines included Engineering, Humanities, Science, Social Science and Business. Coverage of creativity in engineering was found to be incredibly low. Only one course outline out of one hundred and forty four included aspects explicitly related to creativity.

These studies demonstrate that analysis of course outlines is a suitable method for establishing information about engineering programs.

4.2.4.2 Document Analysis

Document analysis is a qualitative research method which involves reading documents and interpreting the information contained within, combining aspects of theme analysis and content analysis (Bowen, 2009). O'Leary (2004, p. 181) defines document analysis as the “collection, review, interrogation, and analysis of various forms of text as a primary source of research data”. A document may refer to any form of record which includes aspects of text, video or graphics. This includes, but is not limited to: websites, emails, historical documents, photographs, blogs, journals, medical records, safety records, YouTube content, graffiti, legislation, and mobile phone texts (O'Leary, 2014, pp. 245-246). Course outlines are a type of document which can be analysed through document analysis.

Documents can be analysed in a number of ways. For example, researchers may wish to evaluate whether the documents being analysed indicate that some pre-determined metrics have been fulfilled or not. For example, Marquis et al. (2017) evaluated 1184 course outlines to establish whether each course built students’ creativity skills, by comparing the course outline written text to nineteen creativity indicators from a specific tool (e.g. lateral thinking, divergent thinking, self-assessment, teamwork). If the course outline text indicated that the creativity indicator was met, this was recorded to reflect this. Otherwise, the course outline was recorded as showing that the course did not meet the creativity indicator.

This study utilised a similar approach to that used by Marquis et al. (2017). However, whereas Marquis et al. (2017) utilised nineteen creativity indicators, this study utilised two primary metrics which corresponded to the purpose of the study. This is discussed below.

4.2.3 Evaluation Criteria

The first criterion regarded whether the course explicitly and intentionally discussed the concept of creativity and/or innovation within the field of engineering. This included, but was not limited to:
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- Description of how creativity, innovation or idea generation may be a part of the problem solving or engineering process. For example, demonstrating a model of the problem-solving process and highlighting that “developing several alternative solution ideas” (or similar wording) is often modelled as the second of four primary stages.

- Providing information that allows students to understand that there are methods, heuristics or techniques designed to enhance creativity (such as mentioning that Brainstorming or TRIZ exists), but students are not actually shown the detailed process of how to apply such processes.

- Case studies or analysis of people that have worked in engineering-related fields and are considered to have been creative. For example, analysis of what made the person “creative” or “innovative” in the field of engineering, and how the student may learn from this.

- Description of the creative process, or theory about creativity.

The second criterion regarded whether the course explicitly included material on the utilisation or application of creativity-related, processes, heuristics or techniques (i.e. creativity training). This included, but was not limited to:

- Students are shown the detailed process of how to apply specific creativity-related heuristics or techniques by an educator, but may not be required to apply the technique themselves (passive learning).

- Students are expected to apply a nominated creativity-related heuristic or technique to a problem (active learning). It does not matter whether this is assessed or not.

Courses were not to be evaluated as meeting a criterion where the course outline only claimed to meet section 3.3 (“Creative, innovative and pro-active demeanour”) of the Stage 1 competencies set out by Engineers Australia. It was required that the course outline made clear how this aim is actually achieved though course content.

4.2.4 Stages of Evaluation

To evaluate the course outlines, analysis took place in two stages. The first stage was used to reduce to list of courses to those which may include some form of creativity-related material. The second stage was used to refine the list of courses to those which were deemed to meet each of the two criterions.
Figure 4: Data analysis process of courses outlines

During the first stage, an assessor evaluated each of the 919 Australian and 190 New Zealand course outlines to establish whether the course may somehow be reasonably be classified as exposing students to some form of creativity-related material, even if the link may be considered vague. Courses were evaluated to either possibly include creativity-related material or not, depending on the text present in the course outline. Courses which provided a description analogous to that outlined in section 4.2.3 were not excluded. In addition, course outlines which included words related to “creativity” or “innovation” or any derivation (such as “creative”, “innovate”) were not excluded. Only if a course outline clearly did not include creativity-related material was it recorded as such and excluded from further analysis. At the end of the first stage of analysis, eight hundred and seventy-seven Australian and one hundred and seventy-four New Zealand courses were excluded from further analysis. This meant that forty-two Australian and sixteen New Zealand courses were considered to potentially include material related to creativity.

During the second stage of analysis, the list of forty-two Australian and sixteen New Zealand courses that were not excluded after the first stage of analysis was presented to three assessors who had not been a part of the first stage of analysis. This included the course name, course code, name of the host institution, and link to the applicable online course outline for each course. The three assessors were academics from the field of engineering. The three assessors were then provided with the criteria description detailed in section 4.2.3, and asked to objectively evaluate whether each course met each of the two criteria or not. Courses were coded separately for each of the two criteria, meaning that a course was able to meet one criteria and not the other.

Evaluations of the three assessors were then compared. Courses were considered as having met each of the two separate criterions, if two out of the three assessors agreed that it met the criterion. Despite the fact that the three assessors were provided with the detailed criteria description, the method of document analysis is ultimately subjective. Two-thirds agreement
amongst the assessors was chosen, as it suggested that the outcome was likely to be more widely accepted within personnel from the engineering domain as being ‘correct’.

![Data analysis process for Australian (left) and New Zealand (right) course outlines](image)

**Figure 5: Data analysis process for Australian (left) and New Zealand (right) course outlines**

### 4.4 Results

**Table 4: Summary of courses evaluated as meeting each criteria**

<table>
<thead>
<tr>
<th>Country</th>
<th>Host Institutions</th>
<th>Degrees Analysed</th>
<th>Courses Analysed</th>
<th>Courses Meeting Criteria 1</th>
<th>Courses Meeting Criteria 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>25</td>
<td>34</td>
<td>919</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>New Zealand</td>
<td>7</td>
<td>7</td>
<td>190</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

Results of the second stage of analysis can be observed in Table 4. From a total of nine hundred and nineteen Australian course outlines that were analysed, twenty courses were evaluated as meeting criteria 1, while no courses were evaluated as meeting criteria 2. Although some assessors nominated that certain courses met criteria 2, there was never a two-thirds agreement amongst the assessors.

From a total of one hundred and ninety New Zealand course outlines that were analysed, three courses were evaluated as meeting criteria 1, while one course was evaluated as meeting criteria 2.
Figure 6: Number of Australian Courses from Each Year Level Including Creativity-Related Content

Figure 6 shows the breakdown for the number of Australian courses across each year level of study. As can be observed, half of the twenty courses occur during first year of study, while there were a total of four courses which occur during second year of study. Only three third-year and two-fourth year courses were evaluated to explicitly include creativity-related material. For the three courses from New Zealand, one course occurred during first, second, and forth year of study, respectively.

4.5 Discussion

4.5.1 Coverage of Creativity-Related Material

Analysis of the results shown in Table 4 demonstrates that 2.2% (20 out of 919) of the Australian and 1.6% (3 out of 190) of the New Zealand course outlines that were analysed were evaluated to meet the first criteria, and explicitly include creativity-related material based upon the description provided in section 4.2.3.

The twenty Australian courses were spread across seventeen degree programs hosted by seventeen tertiary institutions. Given that the overall analysis covered thirty-four degree programs hosted by twenty-five tertiary institutions, it is apparent that approximately half of the electrical engineering programs in Australia, and two-thirds of the tertiary institutions in Australia, encompassed at least one course which included creativity-related material. The three New Zealand courses were hosted by two tertiary institutions.

Reflecting upon Figure 6, it is apparent that where creativity material is covered within a degree program, it is most likely to be included within a course situated within the first or second years of the degree program.

It is evident that explicit inclusion of creativity-related material within course outlines of Australian electrical engineering and New Zealand electrical and electronic engineering
programs, is quite limited. This finding reflects that of previous studies including those which have been discussed above in section 4.1.1. For example, in their study which included analysis of one hundred and forty-four engineering course outlines at a Canadian tertiary institution, Marquis et al. (2017) found that only one course outline explicitly included mention of creativity material. This clearly demonstrated that coverage of creativity throughout the institution’s engineering programmes was incredibly restricted.

Daly et al. (2014) evaluated that engineering courses tend to have a low focus on divergent thinking skills, and have a very high focus on developing convergent thinking skills. Specifically, it was concluded that there was a lack of instruction on developing students’ abilities to generate ideas, and being more open and willing to search for new or alternative ideas. This was in spite of the fact that the seven courses which were analysed had “stated the goal of fostering creativity”.

Further research by Daly, A Mosyjowski, and Seifert (2016) investigated six engineering courses that were considered to have “emphasis on developing creative skills” at a mid-western university in the United States. Fourteen pedagogical approaches for development of the creative process were investigated. It was concluded that while the courses widely covered (in at least 5 out of 6 courses) skill building, domain knowledge and major team projects, all other pedagogical approaches were poorly covered (covered in maximum of 1 course). In particular, the courses lacked discussion on relevant theories of the creative process, did not engage students in self-reflection, did not engage students in risk and failure experiences, did not engage students in creative in novel contexts, and had low cross-disciplinary focus. In addition, open-ended assignments were only present in two of the six courses, showing that students did not have a lot of opportunity to use their creativity skills in settings which really allowed it.

Other researchers have found that engineering students perceive that inclusion of creativity related material in engineering curricula is very low or non-existent (Carpenter, 2016; Gaudron & Kövesi, 2017; Kazerounian & Foley, 2007; Martin-Erro et al., 2016). In a study which investigated the perceptions of college students from several disciplines towards creativity in their program of study, Daly, Mosyjowski, et al. (2016) found that engineering students rated that their degree program had less influence on developing their creativity skills, than students from all the other disciplines. This included the disciplines of arts, education, humanities, and social science. Daly, Mosyjowski, et al. (2016) reports that engineering students commented that courses on design, or design experiences were common ways in which they were able to utilise and build upon their creativity skills.

In is important to highlight that this does not reflect that engineering students see creativity as unimportant, or that their perception about the importance of creativity coverage positively correlates to whether they perceive creativity is well covered or not. On the contrary, Gaudron and Kövesi (2017) found that students considered creativity to be of high importance, but perceived that the level of integration into curricula was incredibly low.

In contrast to the above mentioned studies which report low coverage of creativity within curricula, Marquis and Henderson (2015) reported that 33.8% of instructors (across several
disciplines) reported that creativity was a named learning outcome in course which they teach. However, as has been previously reported (Daly, A Mosyjowski, et al., 2016; Daly et al., 2014; Kazerounian & Foley, 2007), just because educators may consider that courses which they teach develop creativity, this does not mean creativity is likely to effectively developed as a result of studying the courses. Tertiary institutions may also consider that their courses are designed to enhance creativity, but this assertion does not always hold up when the courses are evaluated according to creative theory (Marquis et al., 2017).

Overall, it is apparent that creativity is given low priority or coverage within engineering curricula in Australia and New Zealand, and that this finding is reflective of existing literature, including studies from Canada (Marquis et al., 2017), and the United States (Carpenter, 2016; Daly et al., 2014; Davis & Amelink, 2016; Kazerounian & Foley, 2007), France (Gaudron & Kövesi, 2017), and Spain (Martin-Erro et al., 2016).

4.5.2 Coverage of Creativity Training Material
A study by Marquis and Vajoczki (2012) investigated the perceptions of college teaching staff across several disciplines towards creativity. It was found that "generation of multiple ideas/outcomes" was the most commonly selected factor by engineering instructors that was relevant to creativity. In other words, engineering instructors considered ideation as very relevant to creativity. In comparison, Waller (2016) reports that within the context of engineering, engineering students were most likely to define creativity as "problem solving", "ideation", "thinking outside the box", "critical thinking", "designing", and "modification" in order of most common to least common. These studies demonstrate that both engineering instructors and engineering students are likely to associate creativity with idea generation. Therefore, it is reasonable to expect that attempts to enhance creativity within engineering education may be focused on cultivating students’ abilities in ideation.

Indeed, Genco et al. (2012) have previously agreed with this notion, asserting that “creativity, as part of the engineering design curriculum, is typically taught by introducing a set of ideation methods as part of a junior or senior-level, or occasionally a freshman-level design class”. Supporting this assertion are findings of the study by Daly, A Mosyjowski, et al. (2016). Investigating which activities had influenced students’ development of creative process skills during their program of study, Daly, A Mosyjowski, et al. (2016) found that seventy-six percent of engineering students reported that they had been involved in brainstorming. Moreover, brainstorming was the second most-frequent activity (out of a list of thirty-one activities) that students had been involved in, after “building technical skills”.

However, analysis of the results shown in Table 4 shows that that the assertion by Genco et al. (2012) does not accurately reflect the state of creativity within engineering curricula in Australia and New Zealand. None of the nine hundred and nineteen Australian course outlines which were analysed, were evaluated to meet the second criterion. On the other hand, only one of the one hundred and ninety New Zealand courses was evaluated to include content which focused on creativity training. This means that of a total 1109 course outlines that were analysed across Australia and New Zealand, only one course outline explicitly indicated that students were engaged in learning about creativity heuristics.
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When asked to reflect upon their studies and suggest changes to their program of study for developing creativity skills, Daly, A Mosyjowski, et al. (2016) found that (across several disciplines, engineering not separately provided) “more brainstorming” was only suggested by 16 per cent of participants (N=511 total, N=245 from engineering), and ranked ninth out of a list of twenty-seven activities. This may suggest that while students associate idea generation with creativity, students do not necessarily consider engagement in idea generation activities as the most effective means for enhancing their creativity skills.

Overall, this finding demonstrates that electrical engineering programs across Australia and New Zealand considerably lack content which is aimed at exposing students to, and engaging students in, the use of creativity heuristics and techniques.

4.5.3 Why There is Low Coverage of Creativity

The findings of this study raise the question why there are a relatively low number of courses which apparently focus on creativity-related material. There are two primary issues which have been identified, and will be discussed in this section. These include (i) whether engineering students, educators, institutions and accreditation bodies actually want creativity and innovation to be covered in engineering curricula, and (ii) whether engineering educators, institutions, and accreditation bodies want and try to include creativity in curricula, but incorrectly assert that their course(s) actually foster creativity.

4.5.3.1 Do Engineering Students, Institutions, Instructors, Employers, and Accreditation Bodies want Creativity in Curricula?

As previously discussed, creativity is a competency that Engineers Australia requires both engineering graduates and experienced professional engineers to possess. Graduate engineers must possess a “creative, innovative and proactive demeanour” (Engineers Australia, 2017d), while professional engineers must “cultivate an attitude of innovation and creativity to add value for clients or sponsors of the service, process or system” (Engineers Australia, 2014). Engineering New Zealand also requires that professional engineers “demonstrate creativity when proposing solutions” to complex engineering problems. This clearly demonstrates that both accreditation bodies want engineering programs to build creativity skills.

Academic studies have also specifically highlighted that Australian professional engineers and engineering employers place value upon creativity and innovation skills in their employees and colleagues (Male, Bush, & Chapman, 2009b; Nair et al., 2009). These findings suggest that engineering industry wishes for engineering programs to foster creativity and innovation skills.

The Australian Council of Engineering Deans has stated that Australian “engineering programs have a strong emphasis on ... creativity problem solving and innovation” (King, 2008, p. v). This clearly demonstrates that the highest level of engineering departments within Australia want engineering programs to build creativity skills.

When it comes to engineering instructors, there is a less clear consensus. Numerous engineering educators agree with the notion that there is a need for increased focus on creativity and innovation in engineering education (Badran, 2007; Belski, 2015; Chang et al.,
2016; Charyton, 2014; Charyton & Merrill, 2009; Cropley, 2015b; Gardener et al., 2017; Mahboub et al., 2004; Martin-Erro et al., 2016; Morin et al., 2018). Some educators have also advocated that in order to foster creativity within engineering curricula, creativity should specifically be assessed and commended as a part of assessment tasks (D. H. Cropley & A. Cropley, 2005; Felder, Woods, Stice, & Rugarcia, 2000). However, Marquis and Henderson (2015) found that some engineering educators were adverse to teaching creativity because they felt that it was counter-intuitive to the engineering profession. One instructor encapsulated this viewpoint, stating that “engineering is based on incremental improvements. Radical changes are dangerous to the public’s safety. Creativity—thinking outside the box—will generally lead to negligence” (Marquis & Henderson, 2015). Clearly, while some engineering instructors wish to enhance the focus of creativity in engineering curricula, others may be more sceptical or adverse to such actions. This may make it difficult in certain circumstances for program designers to control how creativity skills are built upon and enhanced throughout a degree.

A recent study by Waller and Strong (2017) investigated engineering students' perceptions of the value of creativity in engineering education. It was concluded that students of all year levels placed high value upon the inclusion of creativity in engineering education. A study by Wickramasinghe and Perera (2010) found that students considered creativity as important for work as a professional, suggesting that participants saw value on inclusion of creativity within engineering curricula. These outcomes demonstrate that students are likely see the value of creativity in curricula and may not be averse to engaging in learning such material.

Overall, while some engineering educators may be averse to dedicating program curricula space to coursework designed to foster creativity skills, numerous engineering educators, as well as engineering deans, students, employers and accreditation bodies consider that it is important. Therefore it is unlikely that, in theory at least, attitudes towards creativity within any level of the engineering education hierarchy are likely to be a severe hindrance.

Constructing an engineering program is challenging and there are numerous decisions that must be made. There are many topics which must be covered, and while creativity may be seen as important, it may simply be given lower priority than other topics. I. Belski et al. (2013) support this viewpoint, asserting that engineering curriculum designers judge there to be insufficient space in an already crowded curriculum for specialised courses which are focused solely on engineering problem-solving and creativity skills.

Reflecting upon the Componential Theory of Creativity, creativity is highly influenced by task motivation which in turn is influenced by external factors such as the social environment. As previously discussed, if a person is surrounded by an environment which places value on creativity, it is likely that this will be conducive and the person’s motivation to be creative will increase. However, it is insufficient that the environment values creativity primarily in name only. The actual environment, in this case courses within engineering curricula, needs to place higher value on creativity (i.e. higher concentration of creativity focused material), so that students are within an environment which is conducive to enhancing creativity through providing both the skills and motivation to do so.
Based upon the findings of this study, it is apparent that if engineering accreditation bodies, institutions, industry, and educators wish to ensure that creativity skills are effectively built throughout an engineering degree, it is important that the level of creativity-related material within engineering degrees needs to be increased. It is important to bear in mind the results of studies such as those conducted by Genco et al. (2012) and Sola et al. (2017) which demonstrate that students' creativity and innovation skills may actually decrease over the period of studying an undergraduate degree. Therefore, without proper creativity focused coursework it is possible that under certain circumstances, educators, institutions or accreditation bodies may assert that a program builds creativity, while students’ skills may in fact do the opposite.

While this may be challenging due to curriculum space constraints, it is insufficient for various levels of engineering education hierarchy to state that creativity is important, but allocate a low priority to creativity in engineering programs.

**4.5.3.2 Do Engineering Educators and Institutions Misidentify How to Enhance Creativity?**

One of the potentially important issues which may influence the apparent coverage of creativity-related material in engineering curricula is differences in opinion of what counts as creativity, and specifically in terms of course outlines, what counts as explicit inclusion of creativity-related material.

As discussed in section 2.2, there have been many definitions of creativity. Moreover, creativity is domain dependant (Baer, 2015), and the way in which instructors may approach teaching creativity may also be specific to the relevant discipline (Marquis & Vajoczki, 2012). What counts as creativity to two people from same discipline may even be very different. This makes it difficult to ensure that even when educators value creativity or attempt to foster creativity in a course which they teach, that it can be widely agreed that the course does actually focus on creativity-related skills.

It is possible that some engineering educators’ view of what counts as creativity may be relatively limited. Some educators associate the concept of ‘creativity’ with skills that are relevant to engineering design (Daly et al., 2014). This is reflected by the findings of Daly, Mosyjowski, et al. (2016), who reports that engineering students commented that courses on design, or design experiences were common ways in which they were able to utilise and build upon their creativity skills. Therefore, educators, institutions and accreditation boards may assume that students sufficiently build their creativity skills through the completion of engineering design courses. If this is the case, it means that students are not explicitly engaged in directly learning about creativity topics such as the creative process, and structured methods or techniques for enhancing their creativity potential.

In several of the studies which have been discussed above, engineering educators asserted that their courses fostered creativity, but upon closer inspection it was found that coverage of creativity was limited (Daly, A Mosyjowski, et al., 2016; Daly et al., 2014; Kazerounian & Foley, 2007; Marquis et al., 2017), especially in the area of divergent thinking.
In the case of Kazerounian and Foley (2007) students reported that they valued creativity but considered that their instructors did not. Meanwhile, the instructors considered that they valued creativity and provided opportunities for developing creativity in their courses but considered that their students did not demonstrate creativity. These findings demonstrated that there may be different views between students and their instructors as to what counts as development of “creativity” skills, and that students and instructors may not be aware of each other’s views about creativity.

The findings of this study suggest that engineering accreditation bodies and tertiary providers may need to expand or adapt their criteria for evaluating how engineering programs foster creativity skills. There may be a need under certain circumstances to encourage that students are explicitly engaged in learning about creative theory and building creativity skills, in addition to implicit methods such as completing engineering design projects.

In addition, it recommended that where necessary, engineering educators spend sufficient time to comprehend such updated requirements and appropriately integrate this into selected/nominated applicable courses which they teach. At a minimum, engineering programs may be adopted to include courses focused on problem-solving and creativity within first and second years of study. The discussion in section 2.8 details how such courses can be effective at enhancing problem-solving and creativity skills. As shown in Figure 6, most Australian courses which include creativity-related content do in fact, occur during first year. However, not all engineering programs include such courses, and the contents of such courses can vary significantly in the extent to which they cover creativity material. This highlights why there may need to be a requirement for accredited engineering programs to include such courses.

Building upon the fact that educators’ views of what may count as creativity may widely vary, it is recommended that requirements for engineering course outlines throughout Australia and New Zealand are updated so that it is explicitly clear when creativity is an intended learning outcome of the course. It is not sufficient that an educator may assert that a certain course fosters creativity, but a reader may have to make an educated guess as to exactly how this is intended to be achieved. While course outlines cannot reasonably include all information about a course, they are expected to convey the intended learning outcomes. If a course outline does not clearly convey information about creativity content, it is clear that creativity is given a low priority in the course and is not a primary learning outcome. If educators wish to assert that the course does foster creativity but do not wish to include it in the course outline, they may need to re-assess the reasons for holding their viewpoint. If creativity is only intended as a minor learning outcome within the course, this should simply be explicitly stated in the course outline.

It is important to bear in mind that it is not reasonable to expect that every course within an engineering curriculum will develop creativity skills. Engineers require comprehensive domain knowledge, and this must be gained through study of numerous applicable courses which may not be appropriate for creativity.
4.5.4 Limitations
There are several limitations of this study which must be addressed.

The point may be raised that many courses were excluded after the first round of analysis. While these numbers may seem initially high, it is important to reflect upon the design of engineering programs. Many engineering courses focus on developing convergent thinking skills, as opposed to divergent thinking skills (Daly et al., 2014). Courses were not eliminated during the first round of analysis if a reasonable link, even if somewhat vague, was present within the applicable course outline. This demonstrates that electrical engineering programs within Australia and New Zealand follow the trend of focusing on domain knowledge and convergent thinking skills.

Another limitation is that this study only considered four-year undergraduate electrical engineering programs within Australia and electrical and electronic engineering programs within New Zealand. It is possible that if postgraduate programs, programs from another engineering discipline (e.g. civil, mechanical), or programs from alternative countries were evaluated, that the results would be different.

A further challenge was that the level of detail, structure, and organisation of course outlines was not standardised across all the institutions. Some institutions provided course outlines which were relatively short at approximately 250 words, while others provided course outlines which were over 1000 words in length. Clearly, providing more detail makes it easier to comprehend the content of the course and whether the course may teach creativity-related material. However, as previously discussed, if development of creativity is a key learning outcome for the course, this should have been clearly stated regardless of the length of the course outline. As discussed in section 4.2.4, course outlines have also been used in numerous studies as a way of evaluating and comparing the content of engineering programs.

4.6 Primary Outcomes and Recommendations
As a result of this study, the following recommendations have been made:

1. Engineers Australia and Engineering New Zealand may wish to consider expanding their criteria for assessing whether engineering programs foster creativity skills or not. Engineering programs may require students to explicitly learn about creative theory and creativity techniques. Expecting that students will sufficiently enhance their creativity skills implicitly though completion of engineering design projects may not to be sufficient means for enhancing creativity skills.

2. Where necessary, engineering educators spend sufficient time to comprehend such updated requirements and appropriately integrate this into selected/nominated applicable courses which they teach.

3. It is recommended that courses focused on developing creativity and problem-solving courses are introduced to first year of study. In addition, creativity material should in general be increased through the engineering program.
4. Tertiary institutions throughout Australia and New Zealand introduce requirements for engineering course outlines, so that it is explicitly clear when creativity is an intended learning outcome of the course.
Chapter 5: Experiment 1 – Creativity Training: Is there a Mode Effect?

5.1 Background

The discussion presented in Chapter 2 outlined that there is sometimes a decline in the creativity skills of engineering students between first and fourth years of studying an undergraduate engineering degree. Moreover, it was established that course material related to creativity and innovation skills is generally rare or given low priority in engineering curricula. The review of Australian and New Zealand electrical engineering programs presented in Chapter 4 demonstrated that creativity indeed is given a low priority within undergraduate engineering programs in Australia and New Zealand (at least in the domain of electrical engineering), reflecting the findings of studies conducted at single institutions in other countries.

In response, it was suggested in Chapter 2 that creativity training may be a way to enhance students’ creativity skills, as it is generally an effective means for doing so. Due to possible restraints in availability of space within the engineering curriculum, it was suggested that students may be able to engage with creativity training in an online-based manner. Website applications which may engage students in creativity have several advantages over traditional classroom settings. These include 24/7 availability, accessibility from anywhere with an internet connection, and the possibility that the training can be either attached to a course or even as a tool which any students can access. This would mean that students interested in creativity training would be able to access it, even if their host institution does not offer it in facet-to-face delivery mode. However, there are also disadvantages which must be taken into account. Website applications take more time, effort and resources to produce and host than traditional pen-and-paper resources. If the application is also not intended for use in a course which focuses on creativity, students may also find it hard to access help or assistance.

From an educator’s standpoint, creativity training software may have several advantages for allowing students to learn about creativity. However, when there is a transition of learning activity from one mode to another, it is required that the learning outcomes of the overall student cohort can be judged to be at least as good using the proposed alternative mode, as the learning outcomes are using the traditional mode. In other words, it must be ensured that if creativity training is computerised, it does not lead to lower learning outcomes than if traditional pen-and-paper or face-to-face setting is used.

5.1.1 Purpose

The primary purpose of this experiment is to provide an answer to Research Question 4 (RQ4). In addition, several factors which may be important for educators to consider when integrating creativity training to engineering curricula are examined. This includes worksheet design, student year level of study, and student enrolment type (local or international student).

This Chapter describes the design of the experiment, materials which were used for the experiment, data analysis method, results of statistical analysis. Discussion of the results and recommendations for educators are provided.
Overall, the results of the experiment will demonstrate that mode does not significantly influence the ideation performance of engineering students, and that computerised creativity training may be an effective way for enhancing creativity skills.

5.1.2 Consideration of Template Design

One of the important considerations when making learning resources, in this case a template to guide participants through applying the Su-Field Analysis procedure, is the design of the template or worksheet itself. This adds a further consideration in addition to the mode which is being used.

In the same way that there are numerous inherent differences between the user-interface experience of using pen-and-paper or computer to complete the same task (Leeson, 2006; Noyes & Garland, 2008), presenting worksheet information in different formats can also influence performance and other outcomes. For example, when designing a template, it is possible that factors such as the overall amount of information or information within a page, the length of the template, the font size, the font style, and line length, can influence learning outcomes.

For example, a study by Katzir, Hershko, and Halamish (2013) investigated the influence of font size, line length and line spacing on the reading comprehension of second and fifth year school students. Katzir et al. (2013) found that line spacing and line length had no influence on the reading comprehension of second year students. On the other hand, fifth year students had higher comprehension scores when the font was smaller, while line spacing and line length had no effect. Tavakoli and Kheirzadeh (2011) evaluated whether font size (10 or 16) influenced the reading comprehension scores of 40 adults aged 17-28, in the context of a reading the same passage of text presented in each font size. Therefore, in this instance, outcomes showed that there was no significant difference in the scores of participants who read the text presented in font size 10 compared to participants who read the text presented in font size 16.

A study by Diemand-Yauman, Oppenheimer, and Vaughan (2011) evaluated whether presenting information in hard-to-read fonts (e.g. *Italics Comic Sans*, *Haettenschweiler*, *Monotype Corsiva*) influenced the extent to which participants remembered the information, compared to when the same was presented in fonts that were more familiar and were easier to read (e.g. Arial). The study included two sections; a controlled laboratory setting, and a follow up study which engaged two hundred and twenty-two students (aged 15-18) at a high school in the United States. During the controlled section, twenty-eight participants were allocated into one of three groups (two hard-to-read fonts, and one easy-to-read font) and provided with 90 seconds to individually read the same passage of text presented in one of the three fonts. Participants were then distracted for fifteen minutes, and then asked to answer a series of questions about the information. Participants who had read the information in the hard-to-read font significantly outperformed the group of students who had read the information presented in the easier-to-read fonts. In the second section of the study, the worksheets and PowerPoint slides of some classes of high school students throughout a term were presented in hard-to-read fonts, while other classes had worksheets and PowerPoint
slides presented in easy-to-read fonts, to act as a control. Evaluation of students’ course assessment results showed that students who were exposed to the information in hard-to-read fonts overall performed significantly better than students who were exposed to the information in easy-to-read fonts. This suggested that, perhaps counter-intuitively, students recalled information better when they had read information presented in a font which required more effort to read. However, it was suggested that usage of hard-to-read fonts may negatively influence motivation which may introduce other issues (Diemand-Yauman et al., 2011). Reflecting on the results of the study, Diemand-Yauman et al. (2011) conclude that “the results suggest that superficial changes to learning materials could yield significant improvements in educational outcomes”.

Overall, the outcomes of these studies demonstrate that numerous factors which may initially seem rather unimportant to the design of worksheets and presented information, may actually have unintended influences on learning outcomes. As a result, it is therefore important to consider the design of templates in the experiment. Two template variations will be investigated in this experiment, to establish whether the different template designs lead to different outcomes or not.

5.1.3 Year Level of Study

An important consideration for educators is not only what students learn about creativity and how they do it (mode, template etc.), but when. As outlined in the Componential Theory of Creativity, domain skills are essential for creativity. Therefore, it is likely that students, who are in later years of study and have accumulated more domain knowledge and skills, will be able to enhance their creativity through this factor which influences creativity. Therefore, it may be more useful to engage students to be engaged in creativity training in their third or fourth year of a four-year engineering degree.

However, there are potential issues with engaging students in creativity training later in their program of study. Exposing students to creativity training earlier in their degree means that they would become more familiar and comfortable with such activities. Students in later years of study may be more hesitant to engaging in such learning activities if they have not previously been exposed to them, especially if they consider they have not needed the knowledge conveyed in creativity training exercises up to that point. Moreover, engaging students in creativity training earlier in their program of study would mean that students have more opportunity to comprehend and utilise material covered in creativity training activities.

Contrary to what may be expected, research has demonstrated that instructional techniques tend to be applied more effectively when the person receiving the instruction actually has less relevant experience (i.e. expertise) in the domain area, compared to when the person receiving instruction has higher levels of expertise in the domain. This phenomenon is known as the expertise reversal effect, and outlines that instructional techniques are most effective when applied to inexperienced learners (Kalyuga, Ayres, Chandler, & Sweller, 2003). Fully guided instructional material may even have a negative influence when used with people or learners who are more experienced (Kalyuga et al., 2003).
Therefore, it is possible that because of the expertise reversal effect, although students from advanced year levels may have more domain knowledge which may increase their creativity, they may also be more hesitant, unwilling or unable to effectively use instructional techniques they are exposed to. In this case, exposing students to creativity techniques early during their program of study would be essential, so that students are willing to accept the concept of learning and making use of creativity techniques.

This experiment will also investigate this possibility by evaluating and comparing the creative performance of first year, third year, and postgraduate students. If the performance of students decreases between first year and following year levels under the same conditions, this may suggest that the expertise reversal effect has taken place and educators need to be wary of this.

5.2 Ethics Approval
Because the experiment would require the participation of human participants, it was required that ethics approval was obtained. A Human Research Ethics Application was submitted to the RMIT College of Science Health and Engineering Human Ethics Advisory Network. Approval was granted, and can be viewed Appendix A. Experiments 2 and 3 were also conducted under this ethics approval.

5.3 Choice of Creativity Technique/Heuristic for Creativity Training
In order to carry out an experiment examining the outcomes of engaging students in creativity training using different modes, it was first required that an appropriate creativity related technique or heuristic was required.

In regards to enhancing the creativity related skills of engineering students, several studies highlighted in Chapter 2 have shown that TRIZ courses run at several institutions worldwide have been successfully at enhancing creative performance and/or self-efficacy (Becattini & Cascini, 2016; I. Belski et al., 2013; Chang et al., 2016). This suggests that engineering educators may consider using TRIZ techniques as the basis for what may be taught in creativity training. However, it is important to comprehend that there are many TRIZ techniques, and they may vary greatly in the level of pre-existing knowlege and skills that are required in order to able to use certain techniques effectively.

From an educator’s perspective, choosing the creativity techniques which will be covered in the creativity training is important. It is essential that any chosen creativity technique has been previously demonstrated to be effective. Ideally, this may be acheived through empirical research and case studies from industry. It is insufficient to expect that just because a creativity technique may be widely utilised, it is actually effective. Not all TRIZ techniques may be effective at enhancing creativity to the same extent, or for the same people.

In considering the possible use of TRIZ techniques, we may reflect upon the study by Belski (2015). Belski (2015) discusses the knowledge and skills required to be able to apply twelve selected TRIZ techniques, including the required existing prior knowledge and practical experience, the time taken to learn the technique, and the complexity of the technique. The twelve techniques are also categorised as being suitable for undergraduate students, postgraduate students, or experienced practitioners. In this context, it is apparent that the
technique should be suitable for undergraduate students to apply. This limits the choice of techniques to the following six TRIZ techniques:

- Method of Smart Little People
- Size-Time-Cost Operator
- Notion of the Ideal Ultimate Result
- Fields of MATCEMIB
- Substance-Field Analysis
- Notion of Resources

Each of these techniques is of low complexity, can be learnt in a few hours (or under) and require low practical experience to use (Belski, 2015). It is important to note that a widely used TRIZ technique, Contradiction Table, does not appear in the list above as it is classified as being suitable for postgraduate students to learn, as opposed to undergraduate students (Belski, 2015).

However, the level of prior knowledge which is required can vary. Method of Smart Little People, Size-Time-Cost Operator, and Notion of the Ideal Ultimate Result all require low levels of prior knowledge to use the technique (Belski, 2015). Analysis of the processes which are used for implementing Smart Little People and Size-Time-Cost Operator shows that neither technique specifically requires the use of knowledge from the problem domain (Gadd, 2011, pp. 15-18). The Ideal Solution/Result method requires analysing what is currently available to be able to try and solve the problem using free resources; again, this does not necessarily require specialised knowledge to use (Gadd, 2011, pp. 181-183). In contrast, the Fields of MATCEMIB and Substance-Field Analysis techniques ideally require use of knowledge from each of the eight fields of MATCEMIB in order to be most effective (Belski, 2007). This means that a practitioner is able to make use of their existing relevant knowledge when solving the problem.

Substance-Field (Su-Field) Analysis is a technique which is primarily aimed at resolving problems of a technical nature (Belski, 2007). This means that it is an suitable technique for engineering students to learn, as many engineering-related problems are of a technical nature.

In educational settings, research has demonstrated that (the Fields of MATCEMIB technique which forms a central part of process to apply) Su-Field Analysis has been effectively used in one-off activities to enhance ideation performance (I Belski et al., 2015; Belski, Skiadopoulos, Aranda-Mena, Cascini, & Russo, 2016; Buskes & Belski, 2017), and has formed part of the content for a TRIZ course which resulted in increased student self-efficacy and self-perception of their performance capabilities (I. Belski et al., 2013).

Su-Field Analysis has also been used by industry companies to effectively find solutions to real problems (Belski, Belski, Chong, & Kwok, 2013; Dobrusskin, Belski, & Belski, 2014). In a review which evaluated the use of TRIZ tools within industry companies based upon analysis of forty-five studies published between 1997 and 2003, Moehrle (2005) found that Su-Field Analysis had been used by industry companies in fourteen of the studies. Ilevbare, Probert, and Phaal (2013) conducted a worldwide survey of forty TRIZ enthusiasts through
online surveys posted on two select TRIZ groups on the LinkedIn social networking website. Respondents were asked how often they made use of a selection of specified TRIZ tools, including Su-Field Analysis. Of the forty participants, nine responded that they used Su-Field Analysis ‘always’ or ‘often’, while only ten participants indicated that they never made use of Su-Field Analysis. These studies demonstrate that Su-Field is a useful TRIZ technique, and it is a tool which is actively used by some companies and individuals within industry to resolve problems.

After reflection upon these outcomes, Su-Field Analysis was chosen as the creativity technique that would be used in the experiment. It is appropriate for the level of knowledge that first-year engineering are expected to possess (Belski, 2015), can be taught in few hours (Belski, 2015), and is evidently useful for application in industry under the correct circumstances.

As a result, it was decided that Su-Field Analysis was an appropriate creativity technique to use in the experiment due to its previous success in enhancing creativity performance in engineering students. Specifically, the experiment would make use of the process to apply Rule 1 of systematised Su-Field Analysis as set out by Belski (2007, pp. 43-56).

Throughout the rest of this Chapter, “Su-Field Analysis” will be used specifically to refer to Rule 1 of systematised Su-Field Analysis as set out by Belski (2007, pp. 43-56), for brevity.

5.4 Experiment Details

5.4.1 Background
The procedure for this experiment was based upon the procedure used in the experiment in the study by Belski et al. (2014) and the follow-up studies which replicated the experiment (I Belski et al., 2015; Belski, Livotov, et al., 2016; Belski, Skiadopoulos, et al., 2016; Buskes & Belski, 2017).

In both the initial study and all follow-up studies, the Fields of MATCEMIB technique significantly increased the number of ideas that were generated over a control group. This included engineering students from Australia (Belski et al., 2014; Buskes & Belski, 2017), Finland, Russian Federation, and the Czech Republic (I Belski et al., 2015), Germany (Belski, Livotov, et al., 2016), and Italy (Belski, Skiadopoulos, et al., 2016). The studies contained a mix of both undergraduate and postgraduate students.

It is possible to examine the study by Belski et al. (2014) (and follow-up studies), to reflect upon how the interventions specifically aimed to enhance creativity according to the Williams Model (discussed in section 2.9.3). It is apparent that in evaluating the question of whether exposing students to simple ideation heuristics can influence ideation performance, these studies evaluate students’ performance based upon the dimensions of fluency (number of ideas) and flexibility (breadth of ideas), both of which are aspects of divergent thinking.

As the aim of creativity training within the context of this experiment is to encourage students to enhance their abilities to generate new ideas and help to overcome the issue of design fixation (discussed in section 2.7.4), it is apparent that these dimensions of divergent thinking
are also suitable assessing student performance in the context of this experiment. Although the divergent thinking dimensions of elaboration and originality are also important, it is important that students can first increase their creative abilities by thinking more broadly to generate more ideas, and ideas which are more varied in nature. As a result, elaboration and originality will not be evaluated in this experiment. Therefore, based upon the Williams Model, the creativity training in this experiment specifically aims to enhance creative thinking skills by focusing on the fluency and flexibility dimensions of creativity.

Table 5: The eight fields of MATCEMIB used in systematised Su-Field Analysis (Belski, 2007, p. 17)

<table>
<thead>
<tr>
<th>Fields</th>
<th>Some Interactions and Substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Gravitation, collisions, friction, direct contact, vibration, resonance, shocks, waves, gas/liquid dynamics, wind, compression, vacuum, mechanical treatment and processing, deformation, mixing, additives, explosion.</td>
</tr>
<tr>
<td>Acoustic</td>
<td>Sound, ultrasound, infrasound, cavitation.</td>
</tr>
<tr>
<td>Thermal</td>
<td>Heating, cooling, insulation, thermal expansion, phase/state change, endo-exo-thermic reactions, fire, burning, heat radiation, convection.</td>
</tr>
<tr>
<td>Chemical</td>
<td>Reactions, reactants, elements, compounds, catalysts, inhibitors, indicators (pH), dissolving, crystallisation, polymerisation, odour, taste, change in colour, pH.</td>
</tr>
<tr>
<td>Electric</td>
<td>Electrostatic charges, conductors, insulators, electric field, electric current, superconductivity, electrolysis, piezo-electrics, ionisation, electrical discharge, sparks.</td>
</tr>
<tr>
<td>Magnetic</td>
<td>Magnetic field, forces and particles, induction, electromagnetic waves (X-ray, Microwaves, etc.), optics, vision, colour/translucence change, image.</td>
</tr>
<tr>
<td>Intermolecular</td>
<td>Subatomic (nano) particles, capillary, pores, nuclear reactions, radiation, fusion, emission, laser, intermolecular interaction, surface effects, evaporation.</td>
</tr>
<tr>
<td>Biological</td>
<td>Microbes, bacteria, living organisms, plants, fungi, cells, enzymes.</td>
</tr>
</tbody>
</table>

In both the initial study and all follow-up studies, the creativity technique used was not Su-Field Analysis, but the Fields of MATCEMIB. The Fields of MATCEMIB alone is simpler and can be used without training, whereas the Su-Field Analysis process requires training. However, since the Fields of MATCEMIB technique was shown to effective throughout many studies, and forms a central part of the systematised Su-Field Analysis Process (Belski, 2007), it was reasoned that Su-Field Analysis would also be effective at enhancing creativity/ideation performance.

Due to the fact that the aims and objectives of this experiment were clearly different to those of Belski et al. (2014) and the follow-up studies, additional resources needed to be created for this experiment. This included making a pen-and-paper template and a computerised version of this template which would allow the presence of a mode-effect to be investigated.
Additionally, students would need to be provided with some form of standardised training to be able to apply the Su-Field Analysis procedure.

### 5.4.2 Overview of Su-Field Analysis (Systematised Rule 1)

Su-Field Analysis can model a problem situation through the use of a standardised approach. Text (optionally placed in circles) is used to describe elements or objects (substances) within the problem, as well as areas of knowledge (fields) (Chang, 2005; Gadd, 2011, pp. 377-380). Arrows are used to show the interaction between the substances and fields, and may be straight, bent, or crossed by lines to show certain traits of the interactions between substances and fields (e.g. something is broken) (Chang, 2005; Gadd, 2011, pp. 379-380).

**Figure 7: Simplest Su-Field Analysis model of a functioning system showing interaction between substances and fields** (Belski, 2007, p. 29; Gadd, 2011, pp. 377-378)

A diagram of the simplest Su-Field Analysis model which shows a functional system with interactions between substances and fields is shown in Figure 7. This triad forms the basis of Rule 1 of systematised Su-Field Analysis by Belski (2007). A short explanation of the process to use Su-Field Analysis and the diagram in Figure 7 will now be provided, to provide the reader with better context. In order to carry out the explanation, an example problem will be used; removing barnacles from a ship’s hull.

In the first stage of Su-Field Analysis, a person must list all the substances which are involved in the problem which is being resolved. For the problem of removing barnacles from a ship, this may be the barnacles and the ship. Next, the person must sketch a general model of the current problem using the Su-Field Analysis triad. This will result in the triad shown in Figure 8. In the triad shown in Figure 8, Substance S1 shows the object or element which is to be influenced, in this case, the barnacles which need to be removed from the ship.
Next, a person must reflect upon the triad and consider how each of the eight fields of MATCEMIB and their suggested interactions shown in Table 5 may be used to resolve the problem. Substance S2 models an object or element which in introduced, in order to remove the barnacles. Field F shows how the introduced substance S2 will be used to influence substance S1, and solve the problem. For example, a hammer may be introduced (S2) to remove the barnacles. This can be acheived through hitting the barnacles with the hammer, introducing a collision interaction which fits within the Mechanical field. An example of the resulting Su-Field Analysis triad is demonstrated in Figure 9.

The fields of MATCEMIB are used as analogies within the Su-Field Analysis procedure. By reflecting upon the fields of MATCEMIB in a systematic manner, a practitioner is able to concentrate more clearly on one concept at a time, and is able to more effectively search their long-term memory for possible solution ideas by thinking about the analogies (Belski & Belski, 2008). A practitioner may have previously seen solutions or concepts used to resolve various other problems in the past. The fields of MATCEMIB triggers the practitioner to think about a wide range of previous solution ideas they have seen (which they may not otherwise have thought about yet), and then allows them to consider whether the previous solution is somehow relevant to the current problem being faced.
5.4.3 **Required Resources for the Experiment**

5.4.3 **Participants**

Participants of the study were undergraduate and postgraduate engineering students who were enrolled in tutorials from appropriate year-level courses focused on engineering design. This included first year undergraduate, third year undergraduate, and postgraduate students who were all enrolled in first year, third year undergraduate, and postgraduate engineering design courses, respectively. All students were from the discipline of electrical and computer engineering.

First year undergraduate and third year undergraduate participants were allocated into either a group which utilised pen-and-paper (PPG) or group which used computers (CBG). This was dependant on whether they had bought a laptop computer to the class or not. All postgraduate students were allocated to a PPG. This means that the method of allocation for first year undergraduate and third year undergraduate participants was non-random and was quasi-experimental. In order to ensure that the groups of each year level may be considered equivalent, participants were requested to complete a questionnaire which was evaluated to test for comparability between the groups. Results showed that groups were equivalent. This is discussed further in detail below in section 5.7.1.

As part of each of the courses on engineering design, there was a week of tutorial classes which covered the topics of problem-solving and creativity within the domain of engineering. As part of these coursework for these tutorial classes, a learning activity involving creativity training was developed. The aim of this activity was to make students aware that there are structured tools to help them model problems and which can help them to consider alternative ideas when resolving a problem.

The creativity training learning exercise was designed to take place during one of these tutorial classes, at the beginning of the class. The experiment was based upon these creativity training learning activities carried out as part of the coursework for these courses.

5.4.4 **Instructional Video for Training**

In order to be able to carry out creativity training, it was required that students would need to be provided with instruction in the use of Su-Field Analysis. In order that students consistently received the same instruction in all tutorial classes, an instruction video was created. The video was 15 minutes in duration and explained how to apply Rule 1 of systematised Su-Field Analysis through demonstration of an example; how to remove annoying flies from the vicinity. The video was created by a TRIZ expert who has substantial experience in using the technique, and teaching the technique at university. A screenshot of the instructional video can be observed in Figure 10.
5.4.5 Problem for Students to Resolve

In order to carry out the creativity learning activity, it was required that a problem which students would attempt to resolve and find solution ideas for, was selected. It was noted that ideally, the problem should be a real issue that is faced somewhere in the world, so that students would be able to make use of their relevant technical knowledge.

The problem which was selected was removing built-up barnacles from the hull of a surface marine ship. This is a process called biofouling, where living marine organisms colonise the surface of a marine vessel when it is not wanted (Salta et al., 2016). This is a real world problem which is faced worldwide by the shipping industry (Oliveira & Granhag, 2016). Biofouling can lead to problems including damage to the ship hull, and increased drag which reduces ship performance, increases fuel consumption, and lowers top speed (Dürr & Thomason, 2009). This increased drag also leads to increased emissions of sulphur dioxide and carbon (Salta et al., 2016). Increased fuel consumption and lower efficiency lead to serious economic issues for shipping companies. Removal of biofouling material is also expensive.

A study by Schultz, Bendick, Holm, and Hertel (2011) investigated the associated cost of dealing with the issue of biofouling on a mid-sized US naval surface ship. It was concluded that a typical level of biofouling on the specified ship type lead to an increased annual fuel consumption of 10.3%. In turn, this lead to additional fuel costs of approximately $1.15 million USD per year. In addition, associated costs such as paint and hull cleaning lead to further costs of approximately $300,000 - $400,000 USD per ship per year. This clearly demonstrates that biofouling is an issue which can cause serious economic and other issues for companies or governments which operate numerous surface ships.

Therefore, the presentation slide presented in Figure 11 was designed. The slide presented a problem scenario whereby biofouling has occurred and barnacles have attached themselves to the hull of a marine ship. Alongside a description of the problem was a picture which visually demonstrated the problem to the reader, so that there was fully clarity about what the problem
entailed. The presentation slide asked the reader to think about how the barnacles could be removed from the ship’s hull, and to record down as many ideas as they were able to think of. To aid working memory and remind the reader about how to apply the Su-Field Analysis technique, a diagram of the Su-Field Analysis triad model for the problem was also placed on the left of the slide.

Figure 11: Problem description presented to students

5.4.6 Pen-and-paper and Computer-based Templates
To be able to carry out the experiment and test whether there is an observable mode-effect between students who engage in creativity training using pen-and-paper and a computerised version, appropriate templates were required which would guide participants through applying the Su-Field Analysis procedure.

Analysis of the template provided for applying Rule 1 of systematised Su-Field Analysis (Belski, 2007, pp. 52-56) shows that the template is quite long, at four pages. This raises the question of whether the template length or design may influence the performance of students, compared to if a shorter template was used. Therefore, third year students who participated in the experiment were split between usage of an extended template, and a shorter, more compact, template.

The extended template for both pen-and-paper and computerised groups was based upon the template provided for applying Rule 1 of systematised Su-Field Analysis (Belski, 2007, pp. 52-56).

The short templates were also based upon the template provided for applying Rule 1 of systematised Su-Field Analysis (Belski, 2007, pp. 52-56). However, stage 4 of the template has been altered to make the section for generating ideas shorter. This is explained below in section 5.4.6.2.

5.4.6.1 Pen-and-paper Extended Template
A copy of the pen-and-paper Su-Field Analysis extended template is located in Appendix F.
The first page includes steps 1 and 2 of Su-Field Analysis, where the practitioner sets out the problem which is being faced, and completes the Su-Field Analysis triad model for the problem. At the bottom of page 1, the Mechanical field and the associated interactions can be seen. As can be observed, the substances and interactions provided in Table 5 have been expanded to include more detailed information. Additionally, there is space between each of the dot points, where ideas can be written down. This separation aids a person to clearly focus on one concept at a time. This is also the approach used for setting out the other seven fields of MATCEMIB on pages 2-4 of the template.

The extended information provided in the dot points, and space between the dot points, is directly based upon the Su-Field Analysis template set out by Belski (2007, pp. 52-56)

5.4.6.2 Pen-and-paper Short Template
A copy of the pen-and-paper Su-Field Analysis extended template is located in Appendix G. The template is based upon the same template that the extended template was also based upon. Steps 1-2 of the short template are the same as for the extended template, and allows a person to model the problem being faced using the Su-Field Analysis triad model.

The difference between the templates was that whereas the extended template sets out the fields of MACTEMIB and their interactions as a long list of bullet points with space between each of them over several pages, the short template was a lot more compact and fits over 1-2 pages. In the short template, the fields of MATCEMIB and their interactions are simply displayed in a single table, similar to that shown in Table 5. Following this table is an entire blank page, where a person can write down all of their ideas.

5.4.6.3 Computerised Extended Template
The computerised extended template which was directly based upon the pen-and-paper extended template used by PPGs. Screenshots of the computerised extended Su-Field Analysis template is located in Appendix G.

Although the computerised template was based upon the pen-and-paper template, it is not possible to transition from one mode to another while ensuring the way the template is displayed and is interacted with, is exactly the same. This difference between modes is discussed in Chapter 4. Accordingly, certain decisions were made to ensure that the computerised template was similar to the pen-and-paper template, but also had certain features which increased usability. For example, there was the decision of how many webpages should be used to make the computerised template, what exactly should be on each webpage, and how a user should be able to move between the webpages.

It was decided that in order to increase cohesion, steps 1 and 2 of the computerised template would be included on the same page, as they are with the pen-and-paper template. Following this, each of the fields of MATCEMIB and their interactions would also be laid out similar to the pen-and-paper version, with space between each of the dot points to write down ideas. During step 1 and 2 of the pen-and-paper template, there is a written generic problem description and generic Su-Field Analysis triad model which contained text (light grey in colour) that was designed to be written over. This allowed for the participant to adjust the
generalised Su-Field Analysis written statement and model triad to the actual problem scenario. On the computerised version, this was implemented through the use of text boxes. When the user updated the appropriate text boxes, the written statement and model triad automatically updated to reflect the problem scenario. For example, when the ‘required outcome’ in step 1 is updated, the text on the model triad between the ‘Barnacles’ and ‘S3’ substances is also updated.

When using pen-and-paper, it is easy for a person to quickly and easily switch between any of the pages from the template. A person does not have to move systematically through each of the fields of MATCEMIB, and can choose to bypass certain fields or randomly access any of the fields at any time with relative ease. To translate this experience to the computerised version, it was decided that users would only see one field of MATCEMIB and their interactions on screen at a time, but the user would be able to directly access any of the fields at any time. Observing the third webpage of the computerised Su-Field Analysis template, it can be observed that this feature was implemented through the use of buttons. When a user clicked an appropriate button to access a different field of MATCEMIB, the webpage changed to display the appropriate field of MATCEMIB and the associated interactions and substances. This also helped users to reduce the need to scroll which can severely influence reading speed (Ricketts & Wilks, 2002). Users were able to transition between the webpages using buttons at the bottom of each webpage.

The fourth webpage of the computerised template included a summary page where the user was able to review all of the ideas which they had generated up until that point. This included the written Su-Field Analysis problem statement, and a list of all the ideas which the user had generated, in a bullet-point list format. This webpage also contained a button whereby the user could submit the ideas they had generated to a database, for later analysis. No data was recorded about the user’s session to the database unless the user pressed the button, ensuring that data was only voluntarily recorded. If a user pressed the button to submit their ideas when they had previously already done so, the existing database record for the user’s session was deleted and a new one was created.

Wang and Nickerson (2017) suggest that software which is designed to support the creativity process should include features to facilitate the user’s working memory. Reflecting upon this recommendation, a feature was implemented whereby the text on the button to access each appropriate field of MATCEMIB would remain red, until at least one idea had generated for that field. This would help users to remember which fields they had already generated ideas for. The first field which users are presented with is the Mechanical field. When the user enters ideas into the Mechanical field then transitions to another field, the button text will then appear black instead of red. If all the generated ideas for a field are deleted, the button text will revert back to red until more ideas are created. Overall, the computerised version was designed so that users would not require prior instruction in how to use the tool.

Although the computer-based template has been created specifically for this experiment, it is useful to reflect upon the framework for designing Individual Creativity Support Systems set out by Wang and Nickerson (2017) discussed in section 3.6.4. Analysis shows that this tool
meets several of the recommendations from the framework. The computerised version includes features such as stimuli that can be used as search cues (i.e. the fields of MATCEMIB and their interactions), use of creativity techniques (Su-Field Analysis) and supporting the function of working memory. This means that the tool provides good support for divergent thinking under the framework. It is also apparent that the tool provides a structured process for carrying out idea generation, but does not provide a structured process for the whole creativity process (problem finding, information finding, idea finding, and solution finding). This is simply due to the limited scope of the experiment focusing on idea finding. Reflecting upon the ways in which a computer can assist in the creative process outlined by Lubart (2005) (discussed in section 3.6.1), it can be argued that the software may be classified as a coach. The software engages the user in a tutorial (the video could be integrated into the tool) and training exercise which are characteristics of software working as a coach (Lubart, 2005). The tool does not allow collaboration, and does not actively suggest any potential solution ideas to the user.

5.4.6.4 Computerised Short Template

The computerised short template was designed as a combination of the computerised extended template and the pen-and-paper short template. Screenshots of the computerised short Su-Field Analysis template is located in Appendix G.

The computerised short template includes most of the same features, layout, and user interaction capabilities as the computerised extended template. The primary difference was that the webpage for generating ideas was different. The webpage for generating ideas was instead based upon the pen-and-paper short template. Observing the fourth webpage shown in Appendix G, it can be seen that the webpage for generating ideas present the user with a table of the fields of MATCEMIB and their interactions (similar to Table 5), and a space beneath to write down all of their ideas.

5.5 Experiment Procedure

This section describes the experiment process. All groups carried out the same process (though some differences on questionnaire existed), the only difference being the mode which they used to carry out the learning activity.

Prior to the commencement of the experiment, participants were made aware that they would be engaged in a creativity training activity during the tutorial class. In addition, participants were made aware that a research project was concurrently being conducted, and that they were able to voluntarily participate in the research project simply by handing back their worksheets to the tutor at the conclusion of the creativity training activity. Students were not informed of the exact nature and objectives of the experiment, in case this may have influenced their performance, and thus the results of the experiment. Students were made aware that their performance would be assessed in order to determine whether the activity was suitable for inclusion into engineering courses.

After students were allocated into their respective groups, members of each PPG were handed a copy of the appropriate pen-and-paper template. Members of each CBG were requested to
open a website which hosted the computerised version of the template, using their laptop browser.

5.5.1 Pre-Experiment Questionnaire
The first page of the pen-and-paper template used by PPG or the first webpage which members of the CBG accessed, were the pre-experiment questionaries. Before the experiment began, all students were requested to complete their pre-experiment questionnaire which can be observed in Appendix H. The questionnaire was different for first year, and third year students. This questionnaire was used to obtain information about students’ habits of using electronic and pen-and-paper resources while studying, and information about their academic performance, problem solving skills, and creativity. This information was later analysed to ensure that there were no appreciable differences between the groups, and that they may be considered equivalent. As discussed below in section 5.7.1, it was established that there was no appreciable differences between the groups, meaning that they may be considered equivalent.

5.5.2 Problem presentation and ideation
After all participants had completed the pre-experiment questionnaire, participants were then shown the presentation slide shown in Figure 11 which detailed a scenario problem of biofouling which had occurred on the bottom of a ship hull. Participants were then provided with sixteen minutes to generate and write down as many ideas as they could, using the templates to help them apply the Su-Field Analysis technique.

Participants worked individually and quietly during the sixteen minutes, and did not communicate with each other or the tutor during this time period. After the sixteen minutes had concluded, participants were requested to complete the post-experiment questionnaire if they intended on submitting the worksheet to the tutor.

Following this, participants were able to voluntarily submit their anonymous work to the tutor to be analysed and included in the data analysis for the experiment. Approximately 90% of the students from each class returned their pen-and-paper templates to the tutor, or submitted their computerised template session data to the database.

5.6 Data Analysis
As previously discussed in section 5.4.1, the creativity training activity which formed the basis of this experiment specifically aimed to enhance the fluency and flexibility dimensions of creativity. Assessment of fluency and flexibility are relatively non-subjective. Fluency can be established by simply counting the number of ideas (Cropley, 2000). Likewise, flexibility can be established by counting the number of categories used to generate ideas (Cropley, 2000). The categories used for scoring flexibility are generally formed in one of two ways. The first way is that an evaluator will assess the ideas and then form categories based upon the ideas. The second way is that an evaluator is presented with a list of categories before starting evaluation, and the evaluator will assign each idea to one of the available categories, if possible.
The method used to establish flexibility in this experiment was based upon the second methodology. Instead of deciding upon their own categories, evaluators used the eight fields of MATCEMIB as categories.

Despite the assertion that evaluation of fluency and flexibility is relatively non-subjective (Cropley, 2000), it was required that the results of evaluation were reliable. However, it is still possible that an evaluator will make subjective interpretations of participants’ ideas. For example, one evaluator may consider that a participant generated five ideas while another evaluator may consider that two of the ideas were very similar, meaning the participant generated four ideas. As a result, three assessors were engaged to independently evaluate the participants’ ideation performance. The evaluators were two academics and one graduate research student from the field of engineering and information technology. If the inter-rater reliability between the assessors was established to be high, the results were able to be deemed reliable and were suitable for carrying out calculations.

In order to evaluate the fluency and flexibility of each participant, each assessor analysed either the handwritten ideas present on the pen-and-paper template, or ideas submitted to the database by the user from their computer-based ideation session. An example page from a participant who completed the pen-and-paper template is available in Appendix I. Ideas submitted to the database by computer-based participants were extracted from the database and placed into a table which allowed assessors to easily evaluate the ideas. An example of this is also available in Appendix I.

Each assessor established the fluency of each participant by establishing the number of independent ideas that the participant had produced. Ideas were considered independent when the solution ideas were distinct and non-redundant. For example, if a participant suggested removing the barnacles by hitting them with a hammer, this would be considered the same idea as hitting them with any other object, as both ideas rely on the concept of direct force. On the other hand, freezing and heating the barnacles or ship both use concept of temperature change, but they attempt to resolve the problem in different ways and are therefore considered as distinct ideas. This meant that there was no maximum value for fluency.

In addition, each independent idea was allocated into one or several fields of MATCEMIB, depending on how the proposed idea aimed to resolve the problem. After analysing all of the ideas, the assessor then established the participant’s flexibility by counting how many fields of MATCEMIB the participant had utilised to generate their ideas. The number of fields used by the participant was set as their flexibility. This meant that flexibility had originally had a maximum value of eight.

However, when the assessors attempted to allocate ideas to the fields of MATCEMIB, there were issues deciding how to allocate certain ideas. Some ideas that were produced by students could arguably be allocated to either the Mechanical or Acoustic field. Likewise, other ideas could arguably be allocated into either the Electric or Magnetic fields.

As a result, it was decided that in addition to the original 8 fields of MATCEMIB, a smaller set of 6 categories would be analysed. For Experiment 1, fluency would be assessed using
both the 8 and 6 categories, in order to establish whether reducing the number of categories would influence the outcomes of Experiment 1 (and future experiments). If reducing the number of categories to 6 did not influence the presence of statistical significance between groups for idea fluency, the number of categories could be reduced to 6 in future experiments with confidence that it was unlikely to influence the findings. This is discussed further in section 5.7.2.

To reduce the original 8 fields to 6, the Mechanical and Acoustic fields were combined to form a Mechanical-Acoustic field, while the Electric and Magnetic fields were combined to form an Electric-Magnetic field.

5.6.2 Inter-rater Reliability

All statistical calculations including inter-rater reliability, average fluency and flexibility of groups, checks for normality of distribution, and checks of statistical significance between groups, were conducted using the Statistical Package for Social Sciences (SPSS) version 23.

The inter-rater reliability of the assessors’ evaluations was then established by calculating Cronbach’s Alpha (Cronbach, 1951) which is one of the most widely used methods of establishing reliability (Peterson, 1994). Inter-rater reliability was established for the entire data set. As can be observed in Table 6, the assessor evaluations for fluency and flexibility were high, with Cronbach’s Alpha values above 0.9. In addition, the assessors’ inter-rater reliability was also compared across all subgroups, to ensure that assessment was consistent across all the groups. As can be observed in Table 7, the assessor evaluations for fluency and flexibility were consistently high, with Cronbach’s Alpha values above 0.9.

Table 6: Evaluation of Inter-rater Reliability

<table>
<thead>
<tr>
<th>Creativity Dimension</th>
<th>Number of Assessors</th>
<th>Participants Assessed</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluency</td>
<td>3</td>
<td>261</td>
<td>0.954</td>
</tr>
<tr>
<td>Flexibility (6 fields)</td>
<td>3</td>
<td>261</td>
<td>0.974</td>
</tr>
<tr>
<td>Flexibility (8 fields)</td>
<td>3</td>
<td>261</td>
<td>0.978</td>
</tr>
</tbody>
</table>

It is important to note that a Cronbach’s alpha value of 0.70, based upon the assertions of Nunnally (1978, p. 245), is often seen as a cut-off or lower limit for accepting reliability in the context of research studies, although some researchers have raised concerns about the way Cronbach’s alpha is interpreted (Panayides, 2013). Nonetheless, these values suggest that inter-rater reliability was especially high. Therefore, the assessors’ evaluations were deemed to be reliable and suitable for further calculations.
<table>
<thead>
<tr>
<th>Year Level</th>
<th>Mode</th>
<th>Template</th>
<th>Participants Assessed</th>
<th>Creativity Dimension</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency</td>
<td></td>
</tr>
<tr>
<td>First Year</td>
<td>PPG</td>
<td>Extended</td>
<td>26</td>
<td>Fluency (6 fields)</td>
<td>0.967</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (8 fields)</td>
<td>0.988</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>Extended</td>
<td>44</td>
<td>Fluency</td>
<td>0.930</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (6 fields)</td>
<td>0.989</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (8 fields)</td>
<td>0.988</td>
</tr>
<tr>
<td>Third Year</td>
<td>PPG</td>
<td>Extended</td>
<td>34</td>
<td>Fluency</td>
<td>0.962</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (6 fields)</td>
<td>0.982</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (8 fields)</td>
<td>0.983</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>Extended</td>
<td>45</td>
<td>Fluency</td>
<td>0.971</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (6 fields)</td>
<td>0.972</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (8 fields)</td>
<td>0.963</td>
</tr>
<tr>
<td>Postgraduate</td>
<td>PPG</td>
<td>Extended</td>
<td>27</td>
<td>Fluency</td>
<td>0.957</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (6 fields)</td>
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<td></td>
<td></td>
<td>Fluency (8 fields)</td>
<td>0.932</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>Extended</td>
<td>11</td>
<td>Fluency</td>
<td>0.964</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (6 fields)</td>
<td>0.937</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (8 fields)</td>
<td>0.998</td>
</tr>
<tr>
<td>Third Year</td>
<td>PPG</td>
<td>Short</td>
<td>42</td>
<td>Fluency</td>
<td>0.957</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (6 fields)</td>
<td>0.967</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (8 fields)</td>
<td>0.961</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>Short</td>
<td>32</td>
<td>Fluency</td>
<td>0.964</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (6 fields)</td>
<td>0.965</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fluency (8 fields)</td>
<td>0.970</td>
</tr>
</tbody>
</table>

In order to carry out further calculations, the three independent data sets from the three evaluators needed to be combined into one data set. In order to achieve this, the fluency and flexibility which a participant was deemed to have achieved was set to the average of the evaluations by the three assessors. For example, if the three assessors evaluated that a certain participant generated 4, 4, and 5 ideas respectively, the average value of 4.33 was set as the number of ideas which the participant had generated. Averaging raters’ evaluations in this manner has been implemented in other studies such as that by Birdi et al. (2012).

An alternative method may be to choose an evaluation with the highest consensus. However, there is significant issue with this method as it may not be possible to achieve consensus. For example, if the assessors independently judged that a student generated 6, 7 and 8 ideas, there would be no highest consensus. Therefore, the using the average of three assessors is highly reasonable method to control for assessor bias when it may not be possible to pick a highest consensus. This is aided by the fact that Cronbach’s Alpha between the assessors’ evaluations is consistently above 0.95.
Table 8: Example Calculation of Creativity Dimensions Using Assessor Evaluations

<table>
<thead>
<tr>
<th>Creativity Dimension</th>
<th>Assessor 1 Evaluation</th>
<th>Assessor 2 Evaluation</th>
<th>Assessor 3 Evaluation</th>
<th>Resulting Allocation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluency</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4.33</td>
</tr>
<tr>
<td>Flexibility</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2.67</td>
</tr>
</tbody>
</table>

5.7 Results

5.7.1 Comparability of Groups
In order that PPG and CBG groups could be compared in terms of ideation performance, it was required that there were no clear differences between each set of PPG and CBG. For example, to compare the influence of mode on ideation performance of first-year students, it was required that there were no clear differences between the first year PPG and CBG.

Groups were compared by evaluating their responses to the pre-experiment questionnaire. These questions can be observed in Table 44 in Appendix H.4, while participants’ responses to these questions can be observed in Table 45. Calculations showed that there were no statistical significances between any set of PPG and CBG on any of the question metrics; this can be seen in Table 46. This established that there were no appreciable differences between any set of PPG and CBG, meaning that the ideation performance of each set of PPG and CBG were able to be compared.

5.7.2 Student Ideation Performance
Table 9: Idea Generation Performance

<table>
<thead>
<tr>
<th>Year Level</th>
<th>Template</th>
<th>Mode</th>
<th>N</th>
<th>Number of Ideas Mean (SD)</th>
<th>Breadth of Ideas (6 Fields) Mean (SD)</th>
<th>Breadth of Ideas (8 Fields) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Year</td>
<td>Extended</td>
<td>PPG</td>
<td>26</td>
<td>10.53 (6.81)</td>
<td>4.33 (1.36)</td>
<td>4.96 (2.00)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>44</td>
<td>7.95 (4.71)</td>
<td>3.47 (1.74)</td>
<td>4.15 (2.32)</td>
</tr>
<tr>
<td>3rd Year</td>
<td>Extended</td>
<td>PPG</td>
<td>34</td>
<td>6.75 (3.98)</td>
<td>3.57 (1.35)</td>
<td>4.50 (1.91)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>45</td>
<td>6.20 (3.29)</td>
<td>3.59 (1.57)</td>
<td>4.06 (1.99)</td>
</tr>
<tr>
<td>Postgraduate</td>
<td>Extended</td>
<td>PPG</td>
<td>27</td>
<td>4.35 (2.48)</td>
<td>3.37 (1.18)</td>
<td>3.81 (1.55)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>11</td>
<td>5.24 (4.63)</td>
<td>3.18 (1.78)</td>
<td>3.66 (2.33)</td>
</tr>
<tr>
<td>3rd Year</td>
<td>Short</td>
<td>PPG</td>
<td>42</td>
<td>7.40 (4.46)</td>
<td>3.77 (1.21)</td>
<td>4.18 (1.46)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>32</td>
<td>6.36 (3.50)</td>
<td>3.59 (1.12)</td>
<td>4.11 (1.46)</td>
</tr>
</tbody>
</table>

The performance of each group of participants in the idea generation activity is shown in Table 9. First year students using the extended template generated a higher number of ideas (i.e. fluency) using pen-and-paper compared to when using a computer (10.53 vs. 7.95 ideas). Likewise, third year students using either template generated a higher number of ideas when using pen-and-paper over computer. Third year students who used the extended template generated 6.75 ideas when using pen-and-paper, but only 6.20 ideas when using a computer. Third year students who used the short template generated 7.40 ideas using pen-and-paper, compared to 6.36 ideas using a computer. On the other hand, postgraduate students generated a higher number when using a computer compared to pen-and-paper (5.24 vs. 4.35 ideas).
In comparison to the values of fluency which ranged between 4.35 ideas on average to 10.53 ideas on average, the breadth of ideas (i.e. flexibility) was more consistent across the groups.

When 6 categories are used for the evaluation of idea fluency, many groups utilised about 3.5 of the 6 fields of MATCEMIB (note that section 5.6 described how the 8 fields were reduced to 6), although postgraduate students utilised on average closer to 3 of the 6 fields.

When 8 categories are used for the evaluation of idea fluency, each group utilised an average of between 3.6 and 5.0 categories to generate ideas.

5.7.3 Influence of Mode on Performance
In order to establish whether there was any influence of mode on the performance of participants, the fluency and flexibility scores of each group were compared. Each group was compared against the other group for which participants were of the same year level, and made use of the same template layout, but the mode was different. For example, the third year group using extended template on pen-and-paper were compared to the third year group using the extended template on computer. The first and postgraduate year students were simply compared to the other group of the same year level, as these year levels only used the extended template.

Table 10: Shapiro-Wilk Test of Normality

<table>
<thead>
<tr>
<th>Year Level</th>
<th>Mode</th>
<th>Template</th>
<th>Creativity Dimension</th>
<th>Shapiro-Wilk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Statistic</td>
<td>df</td>
</tr>
<tr>
<td>First Year</td>
<td>PPG</td>
<td>Extended</td>
<td>Fluency</td>
<td>0.905</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (6)</td>
<td>0.912</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (8)</td>
<td>0.941</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>Extended</td>
<td>Fluency</td>
<td>0.950</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (6)</td>
<td>0.903</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (8)</td>
<td>0.921</td>
</tr>
<tr>
<td>Third Year</td>
<td>PPG</td>
<td>Extended</td>
<td>Fluency</td>
<td>0.943</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>Flexibility (6)</td>
<td>0.927</td>
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<tr>
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<td></td>
<td></td>
<td>Flexibility (8)</td>
<td>0.936</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>Extended</td>
<td>Fluency</td>
<td>0.963</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (6)</td>
<td>0.941</td>
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<td></td>
<td></td>
<td></td>
<td>Flexibility (8)</td>
<td>0.951</td>
</tr>
<tr>
<td>Postgraduate</td>
<td>PPG</td>
<td>Extended</td>
<td>Fluency</td>
<td>0.929</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (6)</td>
<td>0.896</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (8)</td>
<td>0.906</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>Extended</td>
<td>Fluency</td>
<td>0.814</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (6)</td>
<td>0.914</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (8)</td>
<td>0.917</td>
</tr>
<tr>
<td>Third Year</td>
<td>PPG</td>
<td>Short</td>
<td>Fluency</td>
<td>0.844</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (6)</td>
<td>0.962</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (8)</td>
<td>0.980</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>Short</td>
<td>Fluency</td>
<td>0.927</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (6)</td>
<td>0.962</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Flexibility (8)</td>
<td>0.975</td>
</tr>
</tbody>
</table>

* Significant at the <0.05 level. **Significant at the <0.01 level.
The fluency and flexibility distributions of each group were checked to establish whether they were normally distributed or not. The results which can be observed in Table 10, show that the fluency and flexibility for several groups were not normally distrusted (p<0.05). As a result, non-parametric tests were used to check for statistical significance between groups in regards to the two dimensions of creativity.

The fluency and flexibility of each group was compared to the appropriate group of the same year level, and using the same template, but using the alternative mode. Because some of the distributions were not normally distributed, statistical significance was checked between each set of two groups using the Mann-Whitney U test of significance.

As can be observed in Table 11, results showed that there were no statistical significances between any of the groups compared, for either fluency or flexibility. This suggested that in every comparison case, from a strictly statistical viewpoint, the performance of pen-and-paper and computer based participants may be deemed to be equivalent. However, it is important to note that the p-value for first year students was generally lower than that for other year levels. This may suggest that there was less equivalence between the modes in the case of first year students, than there was for the other year levels.

Table 11: Comparison of Pen-and-paper and Computer Based Performance

<table>
<thead>
<tr>
<th>Year Level</th>
<th>Template</th>
<th>Group 1 Mode</th>
<th>N</th>
<th>Group 2 Mode</th>
<th>N</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Year</td>
<td>Extended</td>
<td>PPG</td>
<td>26</td>
<td>CBG</td>
<td>44</td>
<td>Fluency</td>
<td>-1.174</td>
<td>0.241</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility  (6 fields)</td>
<td>-1.933</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility  (8 fields)</td>
<td>-1.347</td>
<td>0.178</td>
</tr>
<tr>
<td>3rd Year</td>
<td>Extended</td>
<td>PPG</td>
<td>34</td>
<td>CBG</td>
<td>45</td>
<td>Fluency</td>
<td>-0.436</td>
<td>0.663</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility  (6 fields)</td>
<td>-0.360</td>
<td>0.719</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility  (8 fields)</td>
<td>-0.967</td>
<td>0.334</td>
</tr>
<tr>
<td>Postgraduate</td>
<td>Extended</td>
<td>PPG</td>
<td>27</td>
<td>CBG</td>
<td>11</td>
<td>Fluency</td>
<td>-0.097</td>
<td>0.924</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility  (6 fields)</td>
<td>-0.299</td>
<td>0.775</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility  (8 fields)</td>
<td>-0.115</td>
<td>0.924</td>
</tr>
<tr>
<td>3rd Year</td>
<td>Short</td>
<td>PPG</td>
<td>42</td>
<td>CBG</td>
<td>32</td>
<td>Fluency</td>
<td>-1.032</td>
<td>0.302</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility  (6 fields)</td>
<td>-0.550</td>
<td>0.583</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility  (8 fields)</td>
<td>0.241</td>
<td>0.809</td>
</tr>
</tbody>
</table>

5.7.3.1 Evaluating Idea Fluency with Six and Eight Categories

It is required to reflect upon the potential decision to reduce the eight fields of MATCEMIB to six categories, which was introduced due to the fact that some ideas cannot be clearly allocated into a specific field (discussed in section 5.6). Reflecting upon the results in Table 11, in each case where PPG was compared to CBG, the difference in idea flexibility was found to be statistically insignificant when eight categories were used.

Further observation demonstrated the results were also statistically insignificant when six categories were used.

Furthermore, the correlation between assessors’ evaluation of idea fluency when six categories were used and assessors’ evaluation of idea fluency when eight categories were
used, was established. Spearman’s rho correlation for all 261 participants of Experiment 1 was 0.962. In addition, the 261 participants were subdivided into groups based upon year level, template and mode (i.e. same groups as in Table 9), and the correlation was calculated on a group-by–group basis. In each case, Spearman’s rho correlation was between 0.944 and 0.986. Overall, these outcomes demonstrate that there was a very high correlation between the assessors’ evaluation of idea fluency when six categories were used, and when eight categories were used.

These outcomes demonstrated that in this case, reducing the eight fields of MATCEMIB into six fields for the purpose of evaluating idea flexibility did not significantly influence the findings. Therefore, it was decided that idea flexibility was to be evaluated using six categories in future experiments instead of eight categories.

It is important to note that the nature of the task that was provided for students to resolve may influence this outcome, and that reduction from eight fields of MATCEMIB to six may not always be suitable.

5.7.4 Influence of Extended versus Short Template on Performance

In order to compare whether the template which participants were provided with (short or extended) influenced performance, the groups of third year participants were analysed.

The fluency and flexibility of PPG and CBG using the extended template were compared, as were the fluency and flexibility of PPG and CBG using the short template. This was done to establish whether the performance of PPG and CBG were the same for each template respectively, so that the PPG and CBG using the same template may be combined for further analysis.

Results of the Mann-Whitney U test of significance showed that the mean values of fluency and flexibility for PPG and CBG using the extended template were statistically insignificant. Likewise, results of the Mann-Whitney U test of significance showed that the mean values of fluency and flexibility for PPG and CBG using the short template were also statistically insignificant. As a result, PPG and CBG using the short template were combined, as were PPG and CBG using the extended template. This allowed all the third year students using the extended template to be compared to all the third year students using the short template. Combining the groups as described resulted in the fluency and flexibility values shown in Table 12.

Table 12: Idea Generation Performance –Short and Extended Templates

<table>
<thead>
<tr>
<th>Year Level</th>
<th>Modes</th>
<th>Template</th>
<th>N</th>
<th>Number of Ideas Mean (SD)</th>
<th>Breadth of Ideas (6 Fields) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3rd Year</td>
<td>Both</td>
<td>Extended</td>
<td>79</td>
<td>6.44 (3.59)</td>
<td>3.58 (1.47)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Short</td>
<td>74</td>
<td>6.96 (4.07)</td>
<td>3.69 (1.17)</td>
</tr>
</tbody>
</table>
Chapter 5: Experiment 1 - Influence of Mode on Creative Performance

Results of the Shapiro-Wilk test of normality showed that the fluency and flexibility of both groups was not normally distributed. Accordingly, non-parametric tests were sued to check for significance between the groups.

Table 13: Comparison of Short and Extended Templates on Performance

<table>
<thead>
<tr>
<th>Year Level</th>
<th>Group 1</th>
<th>Group 2</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Template</td>
<td>Modes</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Year</td>
<td>Extended</td>
<td>Both</td>
<td>79</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Template</td>
<td>Modes</td>
<td>N</td>
<td>Fluency</td>
<td>-0.484</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.628</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flexibility (6)</td>
<td>-0.349</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.727</td>
</tr>
</tbody>
</table>

Results of the Mann-Whitney U test of significance demonstrated that there were no significant differences in performance between the extended and short version templates, based upon either fluency or flexibility.

5.7.5 Influence of Year Level on Performance

In order to compare whether participants’ year level of study influenced their performance during the creativity training activity, the performance of first year, third year and postgraduate students (who used the extended template version only) were compared.

First, the fluency and flexibility of PPG and CBG within each year level were compared. This was done to establish whether the performance of PPG and CBG were the same within each year level, so that the PPG and CBG of each year level may be combined for further analysis.

Results of the Mann-Whitney U test of significance showed that the mean values of fluency and flexibility for PPG and CBG within each year level were statistically insignificant in each case. This allowed the PPG and CBG within each year level to be combined for further analysis. In other words, first year PPG were combined with first year CBG, third year PPG and CBG were combined, and postgraduate PPG and CBG were combined. Combining the groups as described resulted in the fluency and flexibility values shown in Table 14.

Table 14: Idea Generation Performance – Comparison of Year Level

<table>
<thead>
<tr>
<th>Template</th>
<th>Modes</th>
<th>Year Level</th>
<th>N</th>
<th>Number of Ideas Mean (SD)</th>
<th>Breadth of Ideas (6 Fields) Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended</td>
<td>Both</td>
<td>1st Year</td>
<td>70</td>
<td>8.90 (5.68)</td>
<td>3.83 (1.67)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3rd Year</td>
<td>79</td>
<td>6.43 (3.59)</td>
<td>3.63 (1.56)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Postgraduate</td>
<td>38</td>
<td>4.60 (3.21)</td>
<td>3.31 (1.36)</td>
</tr>
</tbody>
</table>

The fluency and flexibility distributions of each group were checked to establish whether they were normally distributed or not. Results of the Shapiro-Wilk test of normality demonstrated that fluency and flexibility were not normally distributed for any of the groups. As a result, non-parametric tests were used to check for statistical significance between groups.
Chapter 5: Experiment 1 - Influence of Mode on Creative Performance

Table 15: Comparison of Year Level on Performance

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year Level</td>
<td>N</td>
<td>Year Level</td>
<td>N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1st Year</td>
<td>70</td>
<td>3rd Year</td>
<td>79</td>
<td>-2.631</td>
<td>*0.009</td>
</tr>
<tr>
<td>1st Year</td>
<td>70</td>
<td>Postgraduate</td>
<td>38</td>
<td>-4.242</td>
<td>*&lt; 0.001</td>
</tr>
<tr>
<td>3rd Year</td>
<td>79</td>
<td>Postgraduate</td>
<td>38</td>
<td>-2.781</td>
<td>*0.005</td>
</tr>
</tbody>
</table>

* Significant at the <0.01 level.

Results of the Kruskal-Wallis test of significance showed that there was statistical significance between the three groups for fluency (p<0.001), but not flexibility (p=0.211). Post-hoc analysis was conducted on fluency between each of the groups in comparison to the other two groups, using the Mann-Whitney U test of significance. The outcomes of these calculations are shown in Table 15. As can be observed, the fluency of first year students is significantly higher than third year students, who in turn have significant higher fluency than postgraduate students.

Figure 12: Mean number of ideas proposed in each field by each year level

Figure 12 demonstrates the number of ideas proposed in each field of MATCEMIB by students of each year level. As can be seen, first year students proposed more ideas in each field of average than third year students, who in turn proposed more ideas in each field on average than postgraduate students. Although the number of ideas generated by students in each year level was different, the ratio of ideas generated in each field (in comparison to the total), was similar for each year level.

It is important to note that a possible interpretation of this result (and limitation of this study) is that the knowledge which is gained throughout completing an engineering degree may not be relevant to the problem which has been presented in the experiment. It is possible that if the problem was different, the results may also be different, where the problem allowed senior students to more effectively utilise the knowledge gained while studying their degree program.
5.7.6 Performance of Local versus International Students

In order to compare whether participants’ mode of enrolment (local or international student) influenced performance, the groups of first year and third year participants were analysed.

Thirteen third year students did not indicate whether they were enrolled as a local or international student. Therefore, these participants were excluded from this specific analysis.

The performance of local and international students from the first year CBG and PPG (both used the extended template) were compared to establish whether the groups could be combined for further analysis. Likewise, the performance of the local and international students from all third year groups (PPG short template, CBG short template, PPG extended template, CBG extended template) were compared to establish whether the groups could be combined for further analysis.

Results of the Mann-Whitney U test of significance showed that the mean values of fluency and flexibility of first year local students from PPG and CBG were statistically insignificant, as were the mean values of fluency and flexibility of first year international students from PPG and CBG. This allowed the first year local students from PPG and CBG to be combined, and the first year international students from PPG and CBG to be combined, for further analysis.

Results of the Kruskal-Wallis test of significance showed that the fluency and flexibility of local students from all four third year groups were statistically insignificant. Likewise, the fluency and flexibility of international students from all four third year groups were statistically insignificant. This allowed all third year local students to be combined, and all third year international students to be combined, for further analysis.

Table 16: Idea Generation Performance – Comparison of Enrolment Type

<table>
<thead>
<tr>
<th>Year Level</th>
<th>Template</th>
<th>Modes</th>
<th>Enrolment</th>
<th>N</th>
<th>Number of Ideas Mean (SD)</th>
<th>Breadth of Ideas Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Year</td>
<td>Extended</td>
<td>Both</td>
<td>Local</td>
<td>59</td>
<td>9.51 (5.51)</td>
<td>3.81 (1.63)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>International</td>
<td>11</td>
<td>5.64 (5.60)</td>
<td>3.45 (1.86)</td>
</tr>
<tr>
<td>3rd Year</td>
<td>Both</td>
<td>Both</td>
<td>Local</td>
<td>111</td>
<td>7.34 (4.00)</td>
<td>3.53 (1.30)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>International</td>
<td>29</td>
<td>4.57 (2.17)</td>
<td>4.07 (1.25)</td>
</tr>
</tbody>
</table>

The fluency and flexibility distributions of each group were checked to establish whether they were normally distributed or not. Results of the Shapiro-Wilk test of normality demonstrated that fluency and flexibility were not normally distributed for any of the groups. As a result, non-parametric tests were used to check for statistical significance between groups.
Results of the tests of statistical significance between groups can be observed in Table 17. Regarding first year students, results of the Mann-Whitney U test of significance showed that there was statistical significance between local and international students for fluency (p<0.01), but not flexibility. Results were similar for third year students, with results showing there was statistical significance between local and international students for fluency (p<0.001), but not flexibility.

Figure 13: Mean number of ideas proposed in each field by third year local and international students

5.8 Discussion

5.8.1 Influence of Mode on Performance
The data gathered from this experiment allows a clear picture regarding how mode may influence performance during creativity training activities. In total, there were four separate tests of whether there was any difference in performance between pen-and-paper and computerised groups. This included first year students, third year students using two variations of a template, and postgraduate students.

Reflecting upon the results from section 5.7.3, outcomes showed that in each of the four cases, the mode used to complete the creativity training activity did not influence the fluency and flexibility performance of students. The performance of first year students was statistically insignificant for both fluency (10.53 for PPG, 7.95 for CBG) and flexibility (4.12...
for PPG, 3.52 for CBG). This outcome was also demonstrated for both groups of third year students. The third year groups which used the extended template had fluency (6.75 for PPG, 6.20 for CBG) and flexibility (3.57 for PPG, 3.59 for CBG) was statistically insignificant. Likewise, the third year group which used the short template had statistically insignificant fluency (7.40 for PPG, 6.36 for CBG) and flexibility (3.77 for PPG, 3.59 for CBG). Despite the fact that there is no statistically significance difference in fluency in any case, the absolute value was always higher for PPG and CBG. However, this trend is reversed when postgraduate students are considered. Postgraduate students generated more ideas using computer over pen-and-paper (5.24 and 4.35, respectively), but again the difference in performance between the groups was statistically insignificant.

Overall, these results clearly demonstrate an outcome which has been repeated several times. In every case, the fluency and flexibility performance was statistically insignificant between PPG and CBG. As a result, it is apparent that specifically within the context of a creativity training activity which was designed to enhance students’ fluency and flexibility capabilities, there was no observable mode effect between students who used pen-and-paper or computer. From an educator’s perspective, this suggests that students are able to engage in creativity training activities as effectively using a computerised version, as they can with a pen-and-paper version. This suggests that computerised creativity training activities may be an alternative way which educators can seek to enhance students’ skills in divergent-based dimensions of creativity, specifically fluency and flexibility.

Reflecting upon the existing literature discussed in Chapter 4, this outcome adds a valuable contribution. Previous studies which have compared the use of pen-and-paper and computer in the context of creativity have primarily focused on understanding whether Decision Support Systems (DSS) can help a person be more creative compared to when they are provided with no additional material or guidance. The context of creativity training where both pen-and-paper and computerised participants are both provided with the same instruction and template design is very different, and has not been thoroughly investigated before.

5.8.2 Influence of Template on Performance
Reflecting upon the results discussed in section 5.7.4, it is apparent that there was no difference in performance between the third year students who used the extended template, and the short template. Fluency was very similar for students who used the extended template (6.96 ideas on average), compared to students who used the short template (6.44 ideas on average), and the difference was statistically insignificant. Likewise, the flexibility of both groups (3.69 for extended template, 3.58 for short template) was similar and also statistically insignificant. This demonstrates that neither the extended or short template negatively influenced students’ ability to effectively perform ideation, compared to the other template.

This raises an interesting question regarding to what extent did the introduction of a template help students to apply the Su-Field Analysis technique. It is possible that students may have been able to effectively apply the technique with only the video instruction, although it is unclear how this may influence their retention and future ability to apply the technique.
While the extended template allows a person to more easily focus on one concept or analogy at a time which can help to reduce cognitive load and improve thinking capacity, this also introduces the disadvantage that template also takes longer to look over or complete. On the other hand, the shorter template presents a lot more information at once. While this means that a person does not need to move through a long template, it may decrease their ability to clearly focus on and properly consider each concept or analogy that is presented.

Su-Field Analysis is a technique which requires a person to consider concepts from a wide array of areas. If the technique is more or less complicated, it is possible that the findings presented here may not be directly transferrable.

5.8.3 Influence of Year Level on Performance
Analysis of the results shown in section 5.7.5 highlighted that the while students’ year level of study did not significantly influence their flexibility performance, fluency was influenced by year level of study. The fluency performance of first year students was significantly higher than that of third year students, who in turn had significantly higher performance than that of postgraduate students.

This outcome suggested that use of Su-Field Analysis did not help students in higher year levels of study to utilise their greater domain knowledge more effectively. Students of all year levels used approximately 3.5 fields of MATCEMIB on average, and although the result was higher for first year students, it was not significantly higher than students of other year levels. Reflecting upon Figure 13, it can be observed that students of each year levels made use of the Mechanical-Acoustic, Thermal and Chemical fields the most. This may be expected; many of the ideas proposed by students were ideas that were familiar to the context of cleaning in general. This included manual removal of the barnacles (mechanical), and the use of chemicals (chemical). Other common ideas included drastically changing the temperature surrounding the ship so that the barnacles die. Example ideas generated by first year students include “use force at an angle (chisel+hammer) to chip barnacles off the hull”, “use hydrochloric acid to dissolve the barnacles“, “move ship to the arctic so barnacles freeze to death” and “pass current through hill, electrocuting the barnacles”. Examples of ideas generated by postgraduate students include “spray toxic gas that has a reaction with the barnacles”, “introduce a bacteria or living organism that can destroy the barnacles” and “burn barnacles through use of fire”. This outcome suggests that while students in first year generated significantly more ideas on average, first year students did not use more areas of knowledge to generate their ideas.

<table>
<thead>
<tr>
<th>First Year Students</th>
<th>Significantly Outperformed (Fluency)</th>
<th>Third Year Students</th>
<th>Significantly Outperformed (Fluency)</th>
<th>Postgraduate Students</th>
</tr>
</thead>
</table>

Figure 14: Fluency performance of students based on year level of study

Instead, it is likely that first year students were able to generate more ideas as they were more willing or able to follow the activity instructions to suggest and write down as many ideas as they were able to. Students in higher year levels may have had greater domain knowledge, but
may have been more reluctant or unwilling to write down ideas which they thought were not suitable, practical, or realistic, or to utilise the Su-Field Analysis technique to its full potential. This process suggests that students in higher year levels may either have been less willing to utilise the suggested technique, or may have engaged in self-judging their ideas before they write them down. This may suggest that students in higher year levels were concurrently engaged in the idea generation and idea evaluation stages of the creative process, instead of solely focusing on the idea generation phase which was the aim of the creativity training activity. While selection of appropriate ideas for resolving the problem is clearly important, it was outside the scope of what this experiment.

In terms of overcoming the issue of ideation fixation and being unable to shift one’s focus and consider other ideas in order to be more creative, this outcome is not ideal. Regardless of whether the cause is because students in higher year levels engage in self-censoring their ideas or whether they are unwilling (or unable) to use the creativity technique, the results suggest that creativity techniques may be most effective when students are exposed to them earlier during their program of study.

Reflecting upon the results, it can be argued that the expertise reversal effect has been observed. It is apparent that some students may suffer from this phenomenon under certain circumstances when introduced to the proposal of learning creativity techniques. The fully guided instructional material (Su-Field Analysis in this case) was most effective when applied by learners who were more inexperienced in solving problems of an engineering nature. Therefore, if educators wish to engage students in creativity training learning activities, it is possible that the highest long-term benefits may be observed if students are in first or second year of study. Engaging students in creativity training earlier within their studies may make the students more willing to adopt and make use of creativity techniques, thus increasing the chances that their creativity skills will enhance by the time they graduate.

A limitation that must be beared in mind is that the postgraduate students involved in the experiment may come from a wide range of backgrounds and have a wide range of experience. While it is possible to directly compare first and third year students as they have so far completed their undergraduate engineering studies at the same institution, postgraduate students may have completed their previous undergraduate studies at a wide range of institutions from different parts of the world. Therefore, their experiences may be different from postgraduate students who have also completed their undergraduate studies at the same institution as they are completing their postgraduate studies.

5.8.4 Influence of Enrolment Status on Performance

As seen above in section 5.7.6, students’ enrolment status is a factor which may influence their ideation performance during creativity training learning activities.

The findings demonstrated that on average, the fluency of local students was significantly higher than the fluency of international students. First year local students generated significantly more ideas on average (9.51 ideas) compared to their international counterparts (5.64 ideas on average), with a medium effect size (Cohen’s d = 0.71). Likewise, third year
local students generated significantly more ideas on average than international students (7.34 ideas, and 4.57 ideas, respectively), with a medium effect size (Cohen’s d = 0.75).

However, when idea flexibility is considered, the findings are different. There was no significant difference between local and international students for fluency, for either first or third year students. This finding suggests that local and international students both used several fields of knowledge to generate ideas, but local students are able to generate more ideas within each of those fields. Reflecting upon Figure 15, it can be seen that this is the case. Although local students generated more ideas in each field of MATCEMIB on average, the ratio of ideas generated within each field compared to the total number of ideas generated was roughly similar for local and international students.

Figure 15: Fluency performance of students based on enrolment status

There are numerous possible reasons as to why local students demonstrated higher fluency that international students. One of the potential reasons is that many international students may have studied English as a second language, whereas the majority of local students are likely to have studied English as a native language. This may have meant that some international students may have had more issues comprehending or making use of some of the concepts listed under the fields of MATCEMIB. The question also arises whether international students may have taken more time to read and complete the extended template. Moreover, a person’s vocabulary is generally lower when utilising a non-native language, and their capability to formulate concepts may be inadvertently reduced as a consequence.

Analysis of data from the third year international students provides insight into this potential issue.

A total of sixteen international third year students used the extended template (both pen-and-paper and computerised), while thirteen international third year students used the short template (both pen-and-paper and computerised). International students who used the extended template had a fluency of 4.96 and a flexibility of 3.92, while international students who used the short template had a fluency of 4.10 and flexibility of 3.92. Analysis established that there was no statistical significance between the groups on either metric. This suggests that international students were able to make effective use of either template.

Further analysis showed that the mode which international students used also did not significantly influence their ideation performance. Third year international students who used pen-and-paper (both templates combined, N=19) had higher fluency, but lower flexibility, than third year international students who used computer (both templates combined, N=10). Analysis again established that there was no statistical significance between the groups on either metric.
Overall, it is apparent that international students demonstrated lower fluency than local students in the creativity training activity. However, it has been established that neither the mode which international students used, not the template which they used, significantly influenced their ideation fluency or flexibility. These findings suggest that international students may see reduced benefits of creativity training activities than local students. Educators therefore need to be aware that creativity training in some circumstances may not be as well received by international students, who may find it to be less useful than local students.

5.8.6 Conclusion and General Remarks
The outcomes of this experiment suggest that computerised creativity training activities are a potential suitable alternative way for teaching creativity skills to engineering students. This leads to the conclusion that creativity training activities may be adapted from classroom settings to an online setting. The instructional training video required to explain and demonstrate usage of the creativity technique can be hosted online as part of any online tool which is developed.

Online creativity training would mean that dedicated software would not be needed to complete the training activity, as any computer with a modern web browser would be sufficient. This increases accessibility and availability of the learning resource (i.e. the instructional video and templates) to students. There is also the possibility for educators to engage students in creativity training outside of class time, helping to meet the issues of crowded engineering curricula. It also provides the possibility that educators may make creativity training activities online so that students who are not required to complete such activities, or are unable to do so as part of a course at their host institution, may do so if they are interested in engaging in self-directed learning for improving their creativity skills.

5.8.7 Limitations
One of the primary limitations of this experiment was the context under which the experiment took place. This may influence the generalisability of the outcomes.

This experiment was conducted using participants enrolled at an Australian tertiary institution, who were studying engineering programs in the discipline of electrical and computer engineering. There are numerous factors which may influence the results of this experiment, and whether the outcome may be repeatable or applicable at another tertiary institution.

Such factors may include the specific tertiary institution, the country or region where the institution is located, the tertiary institution entry requirements, the year level and age of students (such as mature age students aged 22 or over), the level of previous engineering-related work experience, pre-existing creativity skills of students, and the computer and online familiarity of students.

Also of importance is that convenience sampling was used. Participants who bought their laptop to the tutorial classes were allocated to the appropriate CBG, while other participants were allocated to the appropriate PPG. However, to control for this, the pre-experiment
questionnaire was utilised. Results showed that the groups were statistically insignificant on all metrics, meaning that they may be considered equivalent and suitable for comparison.

### 5.9 Summary and Recommendations

This experiment has resulted in several findings which are important to the possible adoption of computerised creativity training activities in engineering education.

In addition, the outcomes contribute valuable findings to the existing literature through identifying factors which are important to creativity training activities within the context of engineering education.

1. The mode used to complete creativity training learning activities, does not influence students’ ideation performance based upon the creativity dimensions of fluency and flexibility. No such outcome has been reported in the existing literature.
2. The length of the template which guided students through applying the Su-Field Analysis technique did not influence students’ performance based upon the creativity dimensions of fluency and flexibility. No such outcome has been reported in the existing literature.
3. Students in first year were more effective at ideation than third year students, who in turn were more effective at ideation than postgraduate students.
4. International students were less effective at ideation than local students.

These findings have resulted in several recommendations for engineering educators who are looking for ways to increase the creativity of engineering students.

1. Developing online creativity training activities and making them widely available may be one way which the creativity skills of engineering students may be effectively built upon and enhanced throughout an engineering degree. This is especially the case where a host institution otherwise has a lack of creativity related material throughout their engineering curricula. This clearly takes investment of time and resources on the part of the educator, though.
2. If creativity training activities are to be adopted into curricula or made available to students, it is possible that making such activities available earlier in an engineering degree is more beneficial to students. Students in first year of study demonstrated higher ideation performance than third year, and postgraduate year students, suggesting that they were more willing or able to use of instruction in creativity techniques. Therefore, making creativity training available in students’ first year of study is ideal as students may be more willing to engage with the activity, and provides more time throughout their degree when they can practice and make use of the training.
3. International students may not see as much benefit from creativity training activities as local students. Reasoning for this is currently unclear and outside the scope of this study, but may somehow be related to whether students have studied English as a native or second language.
Chapter 6: Experiment 2 – Influence of Creativity Training Mode on Long-term Ideation Performance

6.1 Background and Purpose
Reflecting upon the above mentioned literature discussed in section 2.8, it is apparent that creativity training generally has positive benefits to the creative performance of participants. The meta-analysis of the literature on creativity training published between 1950 and 2004 (Scott et al., 2004) and two literature reviews investigating studies on creativity training published since 2000 (Tsai, 2013; Valgeirsdottir & Onarheim, 2017) all concluded that creativity training is generally an effective means for enhancing creativity performance of participants.

Section 2.8.3 highlighted that there are overall few studies which have evaluated the long-term benefits of creativity training. Even more specific, existing literature does not provide clear insight into whether engaging participants in short (less than an hour duration) standalone creativity training activities may have measurable longitudinal benefits.

This experiment will expand the findings of Experiment 1, to understand how involvement in the Experiment 1 creativity training activity may influence future performance. This involves understanding whether several factors investigated in Experiment 1 (mode and template), influence the long-term ideation performance of participants.

6.1.1 Purpose
The purpose of this experiment is to extend the findings of Experiment 1 to:

1. Establish whether engagement in a standalone creativity training activity can lead to increased future ideation performance, compared to if a person does not engage in creativity training.
2. Establish whether the mode used in the creativity training activity has any influence on long-term ideation performance of participants.
3. Establish whether the template used in the creativity training activity has any influence on long-term ideation performance of participants.

6.2 Experiment Details

6.2.1 Participants
Participants of the experiment were third year engineering students enrolled in a course on engineering design. This was the same course which third year participants of Experiment 1 were enrolled in.

Like Experiment 1, Experiment 2 took place in tutorial classes which formed part of the course on engineering design.
6.2.2 Longitudinal Timeframe
Experiment 1 was conducted at the start of the twelve week course, while Experiment 2 was conducted towards the end of the course. The longitudinal time between the two experiments was eleven weeks.

Therefore, this experiment investigated whether engaging students in creativity training of less than an hour duration, lead to measurable benefits to ideation performance after a period of eleven weeks.

6.2.3 Control Group
Students who had participated only in this experiment, and not in the previous creativity training from Experiment 1, were used as a control group. This would allow analysis of how participation in the previous creativity training influenced performance, compared to those who had not participated in the previous creativity training.

6.2.4 Required Resources for the Experiment

6.2.4.1 Creativity Technique
In the experiment, participants were not provided with any suggested creativity technique to use during the experiment, and were not provided with templates which guided them through the application of any techniques they may have previously learnt. The aim was to observe whether engagement in Experiment 1 provided participants with skills which they may be able to deploy in situations where they are not provided with any external guidance or assistance.

6.2.4.2 Problem to Be Resolved
The problem which participants were required to resolve was adapted from the problem presented to students in the study by Belski et al. (2014), and follow up studies (I Belski et al., 2015; Belski, Livotov, et al., 2016; Belski, Skiadopoulos, et al., 2016; Buskes & Belski, 2017). The problem presents the scenario of a pipe which has been filled with lime as a result of water flowing through the pipe, causing build up of minerals on the inside of the pipe. This situation leads to potential problems including decreased water flow and pressure, and water contamination. This is a real-world problem faced by communities worldwide.

This problem was originally adapted from the 2014 Engineers Without Borders Challenge which involved the participation of thousands of engineering students from Australia and New Zealand. The challenge presented several problems present at a Nepalese village. One of the problems described was lime build up in pipes: “Another major problem identified in the area is the level of lime build up in pipes. This calcification of pipes has an impact on the communities’ access to water” (Engineers Without Borders, 2018). Providing further detail, the challenge stated that “lime build up in pipes is an issue as it causes pipes to become blocked leading to a drop in water pressure, an increased risk of corrosion and leaks. Your challenge is to come up with a proposal for the prevention of lime build up in pipes and its removal if and when build up occurs” (Engineers Without Borders, 2018). Therefore, this problem was deemed as a suitable engineering-related problem to which students could generate ideas in the experiment.
Figure 16: Problem description presented to students

The presentation slide (see Figure 16) to be shown to participants in the experiment provided a description of the problem. In addition, a picture of a pipe partially filled with lime build up was included to provide participants with a visual representation of the problem, and to help clarify the problem. Instructions were provided for participants to write down as many ideas as they could on the provided template.

6.2.4.3 Template

All participants were to be provided with the same pen-and-paper template, regardless of the template or mode they had utilised during Experiment 1. The reason for this was to ensure that all participants were engaged in the activity in the same context (i.e. using the same template and same mode), to ensure that this would not influence participant’s performance. Therefore, the only factor which would ideally influence their performance would be if they had participated in Experiment 1, and the conditions under which they did so (mode, template, etc.). The template consisted of several pages. A copy of the template can be observed in Appendix J.

The first page of the template was a short pre-experiment questionnaire which asked participants whether they had participated in the previous creativity training (i.e. Experiment 1), and which mode they had used during the previous creativity training. This information was gathered so that participants may be grouped in various ways depending on the mode and template they had used during Experiment 1, in order to carry out statistical analysis. The questionnaire did not ask students which template they had used during Experiment 1 (i.e. short or extended). In Experiment 1, students were not made aware of the existence of an alternative template, as this may have influenced their performance in some way. Instead, this was established based upon the tutorial which each participant was enrolled into, as each third year tutorial group in Experiment 1 used a specified template (short or extended).

The second page of the template was blank, and only provided a space for participants to write down their ideas. Participants were not provided with any suggested creativity technique to use during the experiment, and were not provided with any other external guidance or assistance.
6.3 Experiment Procedure
The experiment procedure is based upon that used in Experiment 1, with several simplifications. In this experiment, participants were not provided with an instructional video.

Prior to the commencement of the experiment, participants were made aware that they would be engaged in a creativity training activity during the tutorial class. In addition, participants were made aware that a research project was concurrently being conducted, and that they were able to voluntarily participate in the research project simply by handing back their worksheets to the tutor at the conclusion of the creativity training activity. Students were not informed of the exact nature and objectives of the experiment, in case this may have influenced their performance, and thus the results of the experiment. Students were made aware that their performance would be assessed in order to determine whether the activity was suitable for inclusion into engineering courses.

After all participants of each applicable class were provided with a copy of the template, they were first requested to complete the pre-experiment questionnaire which can be observed in Appendix I. Following this, participants were presented with the problem shown in Figure 16. Participants were then provided sixteen minutes to generate and write down as many ideas as they could.

Participants were not provided with any guidance or hints as to how they may wish to resolve the problem, as this would have influenced the findings.

Participants worked individually and quietly during the sixteen minutes, and did not communicate with each other or the tutor during this time period. After the sixteen minutes had concluded, participants were requested to complete the post-experiment questionnaire if they intended on submitting the worksheet to the tutor.

Following this, participants were able to voluntarily submit their anonymous work to the tutor to be analysed and included in the data analysis for the experiment. Approximately 90% of the students from each class returned their pen-and-paper templates to the tutor.

6.4 Data Analysis
Participants’ ideas were assessed according to the same methodology as described in Experiment 1.

Three assessors were engaged to individually assess the idea fluency and flexibility of each participant. Each assessor established the fluency of each participant by establishing the number of independent ideas that the participant had produced. As in Experiment 1, the eight fields of MATCEMIB were reduced to six fields (Mechanical-Acoustic, Thermal, Chemical, Electric-Magnetic, Intermolecular, Biological) which were used to establish the flexibility of each participant. In order to do this, each idea proposed by each participant was allocated to one of the six fields. The number of fields which a participant had used to generate ideas was then recorded as the participants’ flexibility, for a maximum value of 6. This is the same procedure as for Experiment 1.
The assessors’ evaluations were then checked for inter-rater reliability using Cronbach’s Alpha (Cronbach, 1951). Inter-rater reliability was established for the entire data set. As can be observed in Table 18, the assessor evaluations for fluency and flexibility were high, with Cronbach’s Alpha values above 0.9. In addition, the assessors’ inter-rater reliability was also compared across all subgroups, to ensure that assessment was consistent across all the groups. As can be observed in Table 19, the assessor evaluations for fluency and flexibility were consistently high, with Cronbach’s Alpha values above 0.8, meaning the evaluations were reliable (Nunnally, 1978, p. 245).

### Table 18: Evaluation of Inter-rater Reliability

<table>
<thead>
<tr>
<th>Creativity Dimension</th>
<th>Number of Assessors</th>
<th>Participants Assessed</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluency</td>
<td>3</td>
<td>90</td>
<td>0.924</td>
</tr>
<tr>
<td>Flexibility</td>
<td>3</td>
<td>90</td>
<td>0.968</td>
</tr>
</tbody>
</table>

### Table 19: Evaluation of Inter-rater Reliability – Subgroups

<table>
<thead>
<tr>
<th>Template Used in Ex. 1</th>
<th>Mode Used in Ex. 1</th>
<th>Participants Assessed</th>
<th>Creativity Dimension</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended</td>
<td>PPG</td>
<td>16</td>
<td>Fluency</td>
<td>0.856</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>17</td>
<td>Fluency</td>
<td>0.942</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16</td>
<td>Flexibility</td>
<td>0.970</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17</td>
<td>Flexibility</td>
<td>0.966</td>
</tr>
<tr>
<td>Short</td>
<td>PPG</td>
<td>28</td>
<td>Fluency</td>
<td>0.924</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>21</td>
<td>Fluency</td>
<td>0.927</td>
</tr>
<tr>
<td></td>
<td></td>
<td>28</td>
<td>Flexibility</td>
<td>0.939</td>
</tr>
<tr>
<td></td>
<td></td>
<td>21</td>
<td>Flexibility</td>
<td>0.991</td>
</tr>
<tr>
<td>N/A (Control)</td>
<td>N/A (Control)</td>
<td>8</td>
<td>Fluency</td>
<td>0.811</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8</td>
<td>Flexibility</td>
<td>0.933</td>
</tr>
</tbody>
</table>

In order to carry out further calculations, the three independent data sets from the three evaluators needed to be combined into one data set. In order to achieve this, the fluency and flexibility which a participant was deemed to have achieved was set to the average of the evaluations by the three assessors. Averaging raters’ evaluations in this manner has been implemented in other studies such as that by Birdi et al. (2012). This is the same process used in Experiment 1.

### 6.5 Results

#### Table 20: Student Idea Generation Performance

<table>
<thead>
<tr>
<th>Template Used in Ex. 1</th>
<th>Mode Used in Ex. 1</th>
<th>N</th>
<th>Number of Ideas Mean (SD)</th>
<th>Breadth of Ideas Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended</td>
<td>PPG</td>
<td>21</td>
<td>3.45 (1.17)</td>
<td>2.57 (0.78)</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>28</td>
<td>3.98 (2.16)</td>
<td>2.70 (1.18)</td>
</tr>
<tr>
<td>Short</td>
<td>PPG</td>
<td>16</td>
<td>4.42 (1.90)</td>
<td>3.13 (0.74)</td>
</tr>
<tr>
<td></td>
<td>CBG</td>
<td>17</td>
<td>4.63 (1.94)</td>
<td>2.78 (0.82)</td>
</tr>
<tr>
<td>N/A (Control)</td>
<td>N/A (Control)</td>
<td>8</td>
<td>2.58 (1.08)</td>
<td>1.83 (0.59)</td>
</tr>
</tbody>
</table>
The performance of each group of participants in the idea generation activity is shown in Table 20, categorised according to the mode and template used in Experiment 1. As can be observed, the number of ideas generated and breadth of ideas by each group that had participated in Experiment 1 was greater than the control group. Participants of the control group generated an average of 2.58 ideas, while participants of every other group generated between 3.45 and 4.63 ideas. In addition, participants of the control group had a breadth of 1.83, while participants of every other group had a breadth of at least 2.57. This suggests that the control group may have performed less effectively that the other groups.

6.5.1 Influence of Creativity Training on Future Performance
In order to establish whether engagement in previous creativity training influenced the performance of participants, the performance of all those who had completed the creativity training was compared to the control group.

Statistical significance between the four groups who had participated in Experiment 1 checked using the Bonferroni Correction test of significance. Analysis showed that the difference in fluency and flexibility between the four groups was statistically insignificant (p<0.05) for both fluency and flexibility. This meant that the four groups were able to be combined into one (for a total group size of eighty-two) for the purpose of further statistical analysis. The control group had a size of eight.

Table 21: Idea Generation Performance – Control and Intervention Groups

<table>
<thead>
<tr>
<th>Participated in Experiment 1</th>
<th>N</th>
<th>Number of Ideas Mean (SD)</th>
<th>Breadth of Ideas Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes (Experimental Group)</td>
<td>82</td>
<td>4.02 (1.80)</td>
<td>2.72 (0.85)</td>
</tr>
<tr>
<td>No (Control Group)</td>
<td>8</td>
<td>2.58 (1.08)</td>
<td>1.83 (0.59)</td>
</tr>
</tbody>
</table>

Table 22: Comparison of participants who had and had not participated in previous creativity training

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participated in Ex. 1</td>
<td>N</td>
<td>Participated in Ex. 1</td>
<td>N</td>
<td>Fluency</td>
<td>-2.498</td>
</tr>
<tr>
<td>Yes</td>
<td>82</td>
<td>No (Control)</td>
<td>8</td>
<td>Flexibility</td>
<td>-2.924</td>
</tr>
</tbody>
</table>

Results of the Shapiro-Wilk test of normality showed that the fluency and flexibility of the group which had previous engaged in creativity training, was not normally distributed. Therefore, the non-parametric Mann-Whitney U Test was used to check for significance between the groups. The results, shown in Table 22, established that the group which had previously engaged in creativity training significantly outperformed the control group both on fluency and flexibility.

6.5.2 Influence of Mode on Future Performance
In order to establish whether the mode used to engage in previous creativity training influenced the performance of participants, the performance of all those who had completed
Chapter 6: Experiment 2 – Influence of Creativity Training Mode on Long-term Ideation

the creativity training using pen-and-paper was compared to those who had completed the creativity training using computer.

The number of ideas generated by the two PPG groups (short and extended template) from Experiment 1 was checked for statistical significance, using the Mann-Whitney U test of significance. Results showed that the fluency of the two groups was statistically insignificant (p<0.05).

In addition, the number of ideas generated by the two CBG groups (short and extended template) from Experiment 1 was checked for statistical significance, using the Mann-Whitney U test of significance. Results showed that the fluency of the two groups was also statistically insignificant (p<0.05).

These outcomes meant that the two PPG from Experiment 1 were able be combined (for a total group size of 44) for further statistical analysis, as could the two CBG from Experiment 1 (for a total group size of 38).

Table 23: Idea Generation Performance – Mode Used in Experiment 1

<table>
<thead>
<tr>
<th>Mode Used in Ex. 1</th>
<th>Template Used in Ex. 1</th>
<th>N</th>
<th>Number of Ideas Mean (SD)</th>
<th>Breadth of Ideas Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPG</td>
<td>Extended &amp; Short</td>
<td>44</td>
<td>3.80 (1.53)</td>
<td>2.76 (0.81)</td>
</tr>
<tr>
<td>CBG</td>
<td>Extended &amp; Short</td>
<td>38</td>
<td>4.27 (2.06)</td>
<td>2.68 (0.90)</td>
</tr>
</tbody>
</table>

Table 24: Comparison of mode used in creativity training, influence on future ideation performance

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Template Used in Ex. 1</td>
<td>Mode Used in Ex. 1</td>
<td>N</td>
<td>Template Used in Ex. 1</td>
<td>Mode Used in Ex. 1</td>
<td>N</td>
</tr>
<tr>
<td>Extended &amp; Short</td>
<td>PPG</td>
<td>44</td>
<td>Extended &amp; Short</td>
<td>CBG</td>
<td>38</td>
</tr>
</tbody>
</table>

Results of the Shapiro-Wilk test of normality showed that the fluency and flexibility of both PPG and CBG were not normally distributed. Therefore, the non-parametric Mann-Whitney U Test was used to check for significance between the groups. The results shown in Table 24 established that there was no significant difference in the groups, based upon either fluency or flexibility.

6.5.3 Influence of Template on Future Performance

In order to establish whether the template used to engage in previous creativity training influenced the performance of participants, the performance of all those who had completed the creativity training using the short template compared to those who had completed the creativity training using the extended template.

The number of ideas generated by the two short template groups (computer and pen-and-paper based) from Experiment 1 was checked for statistical significance, using the Mann-
Whitney U test of significance. Results showed that the fluency of the two groups was statistically insignificant (p<0.05).

In addition, the number of ideas generated by the two extended template groups (computer and pen-and-paper based) from Experiment 1 was checked for statistical significance, using the Mann-Whitney U test of significance. Results showed that the fluency of the two groups was statistically insignificant (p<0.05).

These outcomes meant that two short template groups from Experiment 1 were able be combined (for a total group size of 33) for further statistical analysis, as could the two extended template groups from Experiment 1 (for a total group size of 49).

Table 25: Idea Generation Performance – Mode Used in Experiment 1

<table>
<thead>
<tr>
<th>Mode Used in Ex. 1</th>
<th>Template Used in Ex. 1</th>
<th>N</th>
<th>Number of Ideas Mean (SD)</th>
<th>Breadth of Ideas Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPG &amp; CBG</td>
<td>Extended</td>
<td>49</td>
<td>3.68 (1.67)</td>
<td>2.57 (0.87)</td>
</tr>
<tr>
<td>PPG &amp; CBG</td>
<td>Short</td>
<td>33</td>
<td>4.53 (1.89)</td>
<td>2.95 (0.79)</td>
</tr>
</tbody>
</table>

Table 26: Comparison of template used in creativity training, influence on future ideation performance

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Template Used in Ex. 1</td>
<td>Mode Used in Ex. 1</td>
<td>N</td>
<td>Template Used in Ex. 1</td>
<td>Mode Used in Ex. 1</td>
<td>N</td>
</tr>
<tr>
<td>Extended</td>
<td>PPG &amp; CBG</td>
<td>49</td>
<td>Short</td>
<td>PPG &amp; CBG</td>
<td>33</td>
</tr>
</tbody>
</table>

Results of the Shapiro-Wilk test of normality showed that the fluency and flexibility of both PPG and CBG were not normally distributed. Therefore, the non-parametric Mann-Whitney U Test was used to check for significance between the groups. The results shown in Table 24 established that there was no significant difference in the groups, based upon either fluency or flexibility.

Table 27: Comparison of control group and extended template group from Experiment 1

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Template Used in Ex. 1</td>
<td>Mode Used in Ex. 1</td>
<td>N</td>
<td>Template Used in Ex. 1</td>
<td>Mode Used in Ex. 1</td>
<td>N</td>
</tr>
<tr>
<td>Extended</td>
<td>PPG &amp; CBG</td>
<td>49</td>
<td>N/A (Control)</td>
<td>N/A (Control)</td>
<td>8</td>
</tr>
</tbody>
</table>

Observation of the results in Table 26 may raise the question of whether the long-term benefits of creativity training demonstrated in Table 22, remain when only students who used the extended template version are considered. As a result, the performance of students who used the extended template version was also compared separately to the control group. As shown in Table 27, results of the Mann-Whitney U Test of significance established that performance was still significantly higher than the control group for both fluency and
flexibility. This clearly demonstrated that creativity training significantly increased performance over the control group, regardless of which template was used.

6.6 Discussion

6.6.1 Influence of Creativity Training on Future Performance

The results shown in Table 21 showed that on average, participants who had attended the previous creativity training session eleven weeks prior, generated more ideas compared to the control group (4.02 versus 2.58 ideas on average), and used more areas of knowledge to generate ideas (breadth 2.72 of versus 1.83 on average). Follow up analysis established that the mean number of idea generated by those who had previous creativity training was statistically significantly higher than the control group. In addition, the mean breadth of those who attended the previous creativity training was significantly higher than the control group.

These results demonstrate that participants who attended the previous creativity training clearly outperformed the control group. Adding weight to this evaluation is that the effect size for fluency (Cohen’s $d = 0.83$) and flexibility (Cohen’s $d = 1.03$) were large, with values of over 0.80 (Cohen, 1977). Wolf (1986) asserts that an effect size of over 0.50 is practically significant, and something was very different between the groups being compared.

Overall, it is clear that engaging in the previous creativity training allowed participants to perform more effectively at ideation in the long-term when faced with an engineering-related problem where they may utilise what they previously learnt. This is reflective of the Componential Theory of Creativity, whereby training in the use of techniques and heuristics can influence the creative process. It is important to stress that unlike the studies outlined in section 2.8.4, which typically cover the use of multiple tools over several days or weeks, the previous creativity training was only less than an hour in duration and only involved instruction in one technique. This demonstrates that even short standalone creativity training activities can have long-term measurable benefits, and that creativity training does not necessarily have to be part of a course or cover multiple aspects/techniques of creativity in order to be useful to students.

In addition, none of the studies discussed in section 2.8.4 investigated the long-term effects of completing creativity training activities using different modes. Currently, there is a lack of studies in the existing literature which have investigated the influence of short creativity training activities on long-term ideation performance, and whether the mode used also influences future ideation performance.

6.6.2 Influence of Mode on Future Performance

Building upon the findings of Experiment 1, this experiment aims to establish whether the mode used to engage in creativity training influences to what extent students benefit from the training. Currently there is a lack of studies in the literature which have investigated this.

Reflection of the results shown in Table 23 shows that students who used pen-and-paper in the creativity training generated an average of 3.80 ideas during this session, and used an average of 2.76 fields of MATCEMIB to generate ideas. In contrast, students who used
computer in the creativity training generated 4.27 on average during this session, and used 2.68 fields of MATCEMIB. Results of the Mann Whitney U test of significance shown in Table 24 established that there was no difference between the groups based upon either fluency or flexibility. This demonstrates that one group cannot be said to have performed better than the other.

The performance of the third year pen-and-paper and computerised groups in Experiment 1 was the same, demonstrating that students could engage in creativity training with equivalent ideation performance. Building upon this, this experiment demonstrates that the mode used to engage in creativity training activities does not influence the long-term development of students’ skills. Overall, this provides comprehensive evidence that students can engage in creativity training using either pen-and-paper or computerised templates, and that either mode will lead to enhanced ideation performance in future compared to a control group.

### 6.6.3 Influence of Template on Future Performance

Building upon the findings of Experiment 1, this experiment aimed to establish whether the template length used to engage in creativity training influences to what extent students benefit from the training. Currently there is a lack of studies in the literature which have investigated this.

The results presented in Table 25 shows that students who used the extended template during the Experiment 1 creativity training generated 3.68 ideas on average during this session, and used an average of 2.57 fields of MATCEMIB to generate ideas. In contrast, students who used the short template during the Experiment 1 creativity training generated an average of 4.53 ideas during this session, and used 2.95 fields of MATCEMIB.

Results shown in Table 26 established that the fluency and flexibility of students who used the short template during Experiment 1 were both statistically significantly higher than students who used the extended template during Experiment 1. In addition, the effect size (Cohen’s d) between the groups was 0.49 for fluency and 0.46 flexibility, demonstrating small, but close to medium effect sizes (Cohen, 1977). Effect sizes of over 0.25 are asserted by Wolf (1986) to mean that the result is educationally significant.

Overall, these findings demonstrate that participants of Experiment 1 who used the short template performed more effectively in this ideation session, than those who used the extended template in Experiment 1. Considering that within Experiment 1 participants performed equally effectively using either template (fluency and flexibility were statistically insignificant), and that their performance was now different in this ideation session, it is apparent that the template used to engage in the initial creativity training activity is important. Using the short template in the creativity training led to better future performance. However, as shown in Table 27, use of the extended template in the creativity training still lead to better performance than the control group in this ideation session. This suggests that use of either template still enhances future performance, but that use of the short template is more ideal.
6.6.4 General Discussion

While in an ideal scenario students would be able to regularly engage in creativity training activities over the course of their engineering degree in order to build their creativity skills, this may not always possible due to time and resource constraints. The findings of this experiment demonstrate that engaging students in learning creativity techniques can help them to generate more ideas in the long-term. Even if students are only able to complete creativity training activities several times throughout their engineering degree, this would still allow them to build on their skills each time, and is likely to boost their ideation capabilities. Providing students with the tools (such as Su-Field Analysis) to help them overcome the issue of idea fixation (discussed in section 2.7.4) is important for allowing them to come up with new and original ways to solve problems, helping their ability to drive innovation.

The finding from Experiment 1 established that students can engage equally effectively in creativity training using pen-and-paper or computer. In turn, this experiment builds upon this and established that the mode used to engage in creativity training does not influence future performance, suggesting use of a computer does not negatively influence the development of students’ skills from an educator’s viewpoint.

Overall, this outcome adds credence to the idea that educators may introduce creativity training activities to engineering curricula, or make them available for students to engage with in self-directed learning. Developing online creativity training activities is likely to be a useful way for educators to improve students’ creativity skills, while making the activities easily accessible and available to a large number of students. This is particularly useful if the students would not be able to engage in creativity training otherwise during their program of study.

6.6.5 Limitations

There are limitations which are important to bear in mind when interpreting the results of this study. First, the time between the two idea generation sessions was eleven weeks. It is possible that during this time, factors which were outside of the control of designed experiment may have influenced the idea generation capacity of participants. For example, if a student engaged in some form of further creativity training in the time between the ideation sessions, this may have influenced their performance in the follow-up task. However, it is unlikely that this may have occurred on a wide scale, if at all. Students were not engaged in directly learning about creativity topics during this eleven week period as part of the engineering design course in which they were enrolled. Furthermore, it is very unlikely students would have studied such material in other courses which they were concurrently studying at the tertiary institution.

Due to the anonymous nature of the experiments, participants of the study were not individually tracked between Experiment 1 and Experiment 2. While it was possible to establish whether the mode used in creativity training influenced longitudinal ideation performance in terms of the overall participant cohort, it was not possible to evaluate how mode may influence the longitudinal ideation performance of individuals. Therefore, although from the perspective of an educator there was no observable influence of mode on
longitudinal ideation performance, there may be certain factors which may affect whether there is an influence on an individual level. If participants were tracked between the ideation sessions, it may be possible to identify factors which may introduce a longitudinal mode-effect for individuals. This is a suggested direction for future research.

Another limitation was that not all of the students who participated in Experiment 1 also participated in this study. Overall, based upon the numbers of participants, approximately 54% of those who were engaged in Experiment 1 also engaged in this study. This experiment was conducted in the last week of the semester which may have contributed to this decrease in participation. While the size of each group decreased from the previous experiment, each group was still suitably large to be able to represent their group from Experiment 1.

It is discussed in section 6.3 that participants were not provided with any guidance or hints as to how they may wish to resolve the problem. However, it is important to note that the nature of the experiment may have inadvertently prompted students to think back to the technique they were exposed to during the first experiment. It is possible that if students were faced with a similar problem under different circumstances, that their performance may have been different. An important area for future work would be to track whether students may retain and utilise creativity techniques that they are exposed to early during their studies, and go on to use the techniques later during their studies (such as in final year capstone projects).

A final limitation is that the control group may be considered relatively small. However, there are several considerations which should be made when interpreting the results. The maximum number of ideas generated by any member of the control group was four ideas, while a maximum of 2.67 (note this is average of assessors) categories of MATCEMIB were used to generate ideas. Observing the results in Table 21, it can be seen that these results are in fact very close to the average performance of those who had participated in Experiment 1. In addition, the performance of the control group was similar to another control group of engineering from the same university who were presented with the same problem (Belski et al., 2014), suggesting that the performance of the control group is likely to be reliable. Moreover, the performance of those who participated in Experiment 1 was significantly higher than the control group based on idea fluency and flexibility which large effect sizes. Overall, it is apparent that the creativity training had longitudinal benefits across a range of performance indicators.

6.7 Summary and Recommendations

The outcomes of this experiment contribute valuable findings to the existing literature on creativity training activities within the context of engineering education.

1. Engaging in short, standalone activities of less than an hour duration can lead to measurable long-term benefits to students’ ideation performance. Existing literature focuses on creativity training that is longer in duration and covers discussion of several aspects of creativity, or application of several creativity techniques, as opposed to one technique.
2. The mode used to complete creativity training learning activities does not influence students’ long-term ideation performance, suggesting students may use either mode without negative consequences on the development of skills. No such outcome has been reported in the existing literature.

3. The template design used to complete creativity training activities may influence students’ long-term ideation performance.

Building upon the recommendations from Experiment 1, and this experiment has resulted in several recommendations for engineering educators who are looking for ways to increase the creativity of engineering students.

1. Developing online creativity training activities and making them widely available may be one way which the creativity skills of engineering students may be effectively built upon and enhanced throughout an engineering degree. It is evident that such activities can have long-term measurable benefits to students’ ideation performance, helping to overcome the issue of fixation.

2. It is recommended that worksheet templates which are used in creativity training activities are shorter in length, as opposed to longer in length. While shorter templates may include less information or a more succinct version of applying the creativity technique, it is apparent that this may help students to be able to remember the technique more effectively.
Chapter 7: Experiment 3 – Influence of Mode on Self-Efficacy

7.1 Background and Purpose

7.1.1 Background
This experiment builds upon the literature discussed in sections 2.4.3 and 2.8.2.2 to 2.8.2.3. A brief summary and re-iteration of this literature will first be discussed to provide context.

Self-efficacy can be defined as the confidence which a person has to resolve a specific problem they are facing (Artino, 2012; Schunk, 1995). A person’s self-efficacy strongly and positively predicts their motivation and performance, regardless of the problem domain (Schunk, 1995). Reflecting upon the Componential Theory of Creativity, it is clear that self-efficacy is linked to creative performance. This is reflected in the findings of Puente-Díaz (2016), who identified that there was a positive link between creative self-efficacy and creative outcomes, demonstrating the importance of self-efficacy in relation to creativity.

Harlim and Belski (2015) established that self-efficacy is vital for being willing to engage in unfamiliar problems within engineering, and that self-efficacy is linked to the development of future problem-solving skills. Steiner et al. (2011) reported that the problem-solving self-efficacy of engineering students actually declined between first and fourth years of study during an undergraduate degree. When considered alongside studies which report that engineering students lack confidence in creativity skills (Gardener et al., 2017), it is imperative that courses which include creativity training should also aim to enhance self-efficacy.

Having high self-efficacy is clearly very important to being able to perform effectively in problem-solving situations which require creativity, and to the successful long-term development of relevant skills. Courses which cover creativity-related topics have demonstrated the ability to enhance students’ self-efficacy and confidence in their own creative abilities (Anderson, 2006; Becattini & Cascini, 2016; I. Belski et al., 2013; Dewett & Gruys, 2007; Mathisen & Bronnick, 2009). This shows that in addition to

Section 3.8 highlights that while there are some studies which have investigated the influence of mode on self-efficacy during tests or assessment tasks (Chua, 2012; Chua & Don, 2013; Nikou & Economides, 2016), there are a lack of studies which have evaluated the influence of mode on self-efficacy during creativity training.

7.1.2 Purpose
There are two purposes to this experiment.

The primary purpose of this experiment is to expand the findings of Experiment 1 and evaluate whether the mode which a person uses to engage in creativity training, can influence their self-efficacy during the activity. If using a computer environment negatively influences a person’s self-efficacy during creativity training, this would be an issue. However, if a computerised mode is found to either have no influence or is perhaps even superior to pen-
and-paper, this means that the environment is unlikely to negatively influence self-efficacy and educators may be more confident that computerised creativity training activities are viable.

The secondary purpose of this experiment is to gain understanding of students’ attitudes towards the possible inclusion of creativity training activities in engineering curricula, and if there is a mode which they would prefer to use to engage in creativity training activities. As discussed in section 3.4.3, researchers have evaluated that the way (i.e. mode) in which people prefer to do a task does not necessarily correspond to the way which they perform most effectively in the task. However, as set out in the Componential Theory of Creativity, task motivation is highly influential on creative performance. If students show clear preference for completing creativity training activities using one mode over another, and they are only provided resources to engage in the activity using the mode which they do not prefer, it is likely that their motivation to engage in the creativity training will decrease.

Therefore, from an educator’s perspective it may be apparent that students should use a specific mode to engage in creativity training in order to maximise their learning outcomes (e.g. ideation performance, ability to remember the technique). However, it is possible that the less effective mode should actually be made available to students if they prefer to use that mode, in order to positively influence their motivation and encourage engagement with the creativity training.

### 7.2 Experiment Resources

The design of Experiment 3 was based upon Experiment 1, with some changes.

#### 7.2.1 Participants

Participants of the study were first year engineering students (from the same institution as the participants of Experiments 1 and 2) enrolled in the Aerospace and Mechanical discipline. The experiment took place during a lecture of the course.

Participants who had brought a laptop to the lecture were allocated into the computer-based group (CBG). Participants who had not brought a laptop to the lecture were allocated into the pen-and-paper (PPG) group. To ensure that the groups were comparable, participants were requested to complete the questionnaire shown in Table 31. The questionnaire asked participants to rate their problem-solving skills, problem-solving self-efficacy, creative fluency, familiarity with using computers for study related purposes, and their Australian Tertiary Admission Rank (ATAR) if applicable.

#### 7.2.2 Problem to Solve

The problem which participants were presented with, and were asked to generate ideas to resolve, was the same as the problem used in Experiment 1. The problem presents the situation of biofouling which has occurred on the hull of a marine vessel. Participants were asked to generate as many ideas to resolve the problem as they can and write them down on the provide template. A picture of the presentation slide containing the problem description, photo of a ship with biofouling and instructions for participants, can be seen in Figure 8.
Chapter 7: Experiment 3 – Influence of Mode on Self-Efficacy

7.2.3 Creativity Technique and Instructional Video
The creativity technique that was chosen for students to learn and apply during the creativity training was Su-Field Analysis, as in experiment 1. The results of experiment 2 clearly demonstrated that Su-Field Analysis is an effective technique for students to learn.

In order to teach participants how to use Su-Field Analysis, the instructional video utilised in experiment 1 was also used for this experiment. A screenshot from the instructional video can be seen in Figure 10, while more information can be found in section 5.4.4.

7.2.4 Measuring Self-efficacy
Self-efficacy is defined by Bandura (1986) as ‘people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances’. More generally, self-efficacy can be described as the self-confidence which a person possesses to complete a specific task (Artino, 2012).

In order to measure the influence of mode on self-efficacy during the creativity training activity, participant’s self-efficacy was measured at two points of time using Likert Scale using a pre-test post-test design. Self-efficacy was first measured at the beginning when participants were initially presented with the problem, and then again at the conclusion of the activity. The self-efficacy items used in this study were specifically designed for use in this study.

Reflecting upon the definitions of self-efficacy given by Bandura (1986) and Artino (2012), the questions presented in Table 28 were specifically designed to relate to the context and task that participants were involved in; being presented with a problem to resolve which requires the use of idea generation and creativity skills.

Table 28: Self-efficacy questions students were asked to complete. Likert Scale ranges from 1 (strongly disagree) to 7 (strongly agree).

<table>
<thead>
<tr>
<th>When Question Was Answered</th>
<th>Self-Efficacy Question</th>
</tr>
</thead>
<tbody>
<tr>
<td>When the problem was first presented.</td>
<td>“I am confident that I will be able to effectively resolve the problem I have been presented with.”</td>
</tr>
<tr>
<td>Directly after conclusion of the idea generation session.</td>
<td>“I am confident that I have effectively resolved the problem I was presented with.”</td>
</tr>
</tbody>
</table>

Analysis of the literature demonstrates that 4-point Likert Scales (Becattini & Cascini, 2016), 5-point Likert Scales (I. Belski et al., 2013), and 7-point Likert Scales (Dewett & Gruys, 2007) have been used to evaluate changes in creative self-efficacy using pre-test post-test design. Bandura (2006) asserts that “scales that use only a few steps should be avoided because they are less sensitive and less reliable”. As a result, to increase accuracy over a 5-point Likert Scale while ensuring that the number of categories does not confuse participants, a 7-point Likert Scale was used.
Chapter 7: Experiment 3 – Influence of Mode on Self-Efficacy

7.2.5 Measuring Students Interest in Creativity Training and Preference of Mode
In order to measure students’ interest in the possibility of adopting creativity training activities into engineering curricula, the following question was incorporated into the post-experiment questionnaire: “I would like to have activities like this one available in the future, to assist in developing my problem solving skills”. This was to be answered at the end of the creativity training session, so that students were able to reflect upon their actual experience of a creativity training activity, and not rely on their expectations alone.

In order to measure students’ preference of mode for completing creativity training activities if they are adopted into engineering curricula, the following question was incorporated into the post-experiment questionnaire: “If activities like this one are made available in the future, I would prefer to use a web based interface to engage in the activity, rather than pen-and-paper”.

Both questions were answered on a 7-point Likert Scale ranging from 1 (strongly disagree) to 7 (strongly agree).

7.2.6 Templates
The templates used in Experiment 3 were based upon the short used Experiment 1, with some changes. Experiment 2 demonstrated that in terms of influencing long-term ideation skills, it was more effective for students to use the short template which presented the fields of MATCEMIB and their interactions as a table. Therefore, this was the format that was utilised.

7.2.6.1 Pen-and-paper Template
Steps 1 and 2 of Su-Field Analysis procedure were removed from the template to make it simpler to use. The pen-and-paper template, observable in Appendix K, contained three pages. The first and third pages contained the pre-experiment and post-experiment questionnaires, respectively. At the top of the second page was the question used to gauge participants’ self-efficacy when first faced with the problem. Below this was a table of the fields of MATCEMIB and their interactions, and space for participants to write down all their ideas.

7.2.6.2 Computerised Template
The computerised template followed a similar design to the pen-and-paper template. The first and third webpages contained the pre-experiment and post-experiment questionnaires, respectively. The second webpage contained a table of the fields of MATCEMIB and their interactions, and space for participants to write down all their ideas. The pre-experiment self-efficacy question was included on first webpage, after the pre-experiment questionnaire. Users were able to move between the webpages using buttons at the bottom of each webpage. Users were able to voluntarily submit their ideas to the database for later analysis using a submit button at the bottom of the third webpage. A copy of the computerised template can be seen in Appendix K.

7.3 Methodology
The experiment procedure is based upon that used in experiment 1.
Prior to the commencement of the experiment during the lecture, participants were made aware that they would be engaged in a creativity training activity. In addition, participants were made aware that a research project was concurrently being conducted, and that they were able to voluntarily participate in the research project simply by handing back their worksheets to the tutor at the conclusion of the creativity training activity. Students were not informed of the exact nature and objectives of the experiment, in case this may have influenced their performance, and thus the results of the experiment. Students were made aware that their performance would be assessed in order to determine whether the activity was suitable for inclusion into engineering courses.

First, students were shown the instructional video which demonstrated how to apply the Substance-Field Analysis technique. Please refer to section 5.4.4 for in-depth information about the instructional video.

Students were then allocated into their respective groups. Members of the PPG were handed a copy of the pen-and-paper template. Members of CBG were requested to open a website which hosted the computerised version of the template, using their laptop browser.

After all participants were provided with a copy of the pen-and-paper template or had accessed the computerised template, they were first requested to complete the pre-experiment questionnaire. Following this, participants were presented with the problem shown in Figure 16. Participants were then provided ten minutes to generate and write down as many ideas as they could.

Participants worked individually and quietly during the ten minutes, and did not communicate with each other or the lecturer/tutors during this time period. After the ten minutes had concluded, participants were requested to complete the post-experiment questionnaire if they intended on submitting the worksheet.

Following this, participants were able to voluntarily submit their anonymous work to be analysed and included in the data analysis for the experiment. A total of 22 pen-and-paper participants submitted their worksheets, while 26 computerised participants submitted their ideas to the database.

### 7.4 Data Analysis

The data analysis procedure was the same as that used in Experiment 1. Three assessors independently evaluated the fluency and flexibility of each participant, by evaluating either the handwritten ideas by pen-and-paper participants, or ideas submitted to the database by computerised participants. As before, the eight fields of MATCEMIB were reduced to six, meaning that flexibility was scored out of six.

The fluency and flexibility scores awarded to each participant by the three assessors were then checked for inter-rater reliability. Results shown in Table 29 demonstrate that the evaluations were above 0.96 for both fluency and flexibility, meaning the evaluations were reliable (Nunnally, 1978, p. 245). The fluency and flexibility of each subgroup (based upon mode) were also checked to ensure that results were reliable for each independent group. Results
shown in Table 30 demonstrate that inter-rater reliability remained present when participants were separated according to the mode they had used.

**Table 29: Evaluation of Inter-rater Reliability**

<table>
<thead>
<tr>
<th>Creativity Dimension</th>
<th>Number of Assessors</th>
<th>Participants Assessed</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluency</td>
<td>3</td>
<td>48</td>
<td>0.978</td>
</tr>
<tr>
<td>Flexibility</td>
<td>3</td>
<td>48</td>
<td>0.962</td>
</tr>
</tbody>
</table>

**Table 30: Evaluation of Inter-rater Reliability – Subgroups**

<table>
<thead>
<tr>
<th>Mode Used</th>
<th>Participants Assessed</th>
<th>Creativity Dimension</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPG</td>
<td>22</td>
<td>Fluency</td>
<td>0.973</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flexibility</td>
<td>0.941</td>
</tr>
<tr>
<td>CBG</td>
<td>26</td>
<td>Fluency</td>
<td>0.984</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flexibility</td>
<td>0.976</td>
</tr>
</tbody>
</table>

In order to carry out further analysis, the fluency and flexibility of each participant was set as the average of the three assessors’ evaluations.

### 7.5 Results

#### 7.5.1 Comparability of Groups

**Table 31: Responses to pre-experiment questionnaire**

<table>
<thead>
<tr>
<th>Pre-Experiment Question</th>
<th>PPG Mean (SD) (N=22)</th>
<th>CBG Mean (SD) (N=26)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 I am very comfortable using computers for university related learning activities.</td>
<td>5.91 (1.41)</td>
<td>5.96 (1.43)</td>
<td>0.393</td>
</tr>
<tr>
<td>2 I am very good at problem-solving.</td>
<td>5.45 (1.22)</td>
<td>5.27 (1.11)</td>
<td>0.805</td>
</tr>
<tr>
<td>3 I am certain that I am able to resolve any problem I will face.</td>
<td>4.91 (1.44)</td>
<td>5.15 (1.08)</td>
<td>0.915</td>
</tr>
<tr>
<td>4 I come up with novel ideas all the time.</td>
<td>4.68 (1.55)</td>
<td>4.81 (1.36)</td>
<td>0.576</td>
</tr>
<tr>
<td>5 I always have many concepts for how to resolve a problem I am facing.</td>
<td>5.91 (1.41)</td>
<td>5.96 (1.42)</td>
<td>0.912</td>
</tr>
<tr>
<td>6 Australian Tertiary Admissions Rank*</td>
<td>87.66 (8.06)</td>
<td>84.96 (8.54)</td>
<td>0.478</td>
</tr>
</tbody>
</table>

*Note. A total of 11 and 11 students from PPG, CB provided their ATAR, respectively.*

Evaluation of the responses to the pre-experiment questionnaire demonstrated that there were no appreciable differences between the two groups. The responses of PPG and CBG were compared for each question using the Mann-Whitney U test of significance. In each case, the difference between groups was not statistically significant. This established that there were no appreciable differences between PPG and CBG, meaning that the groups were able to be compared.
7.5.2 Student Ideation Performance

Table 32: Student Idea Generation Performance

<table>
<thead>
<tr>
<th>Mode Used</th>
<th>N</th>
<th>Number of Ideas</th>
<th>Breadth of Ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPG</td>
<td>22</td>
<td>5.68 (3.70)</td>
<td>3.19 (1.39)</td>
</tr>
<tr>
<td>CBG</td>
<td>26</td>
<td>4.12 (3.11)</td>
<td>2.64 (1.48)</td>
</tr>
</tbody>
</table>

The ideation performance of PPG and CBG are presented in Table 32. PPG generated 5.68 ideas on average, and used an average 3.19 of the six fields of MATCEMIB. Meanwhile, CBG generated an average of 4.12 ideas, and used an average of 2.64 fields to generate ideas.

Results of the Shapiro-Wilk test of normality showed that the fluency and flexibility of CBG were not normally distributed. Therefore, the non-parametric Mann-Whitney U Test was used to check for significance between PPG and CBG. The results shown in Table 33 established that there was no significant difference in the groups, based upon either fluency or flexibility.

Table 33: Comparison of ideation performance of PPG and CBG

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode</td>
<td>N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PPG</td>
<td>22</td>
<td>Fluency</td>
<td>-1.492</td>
<td>0.136</td>
</tr>
<tr>
<td>CBG</td>
<td>26</td>
<td>Flexibility</td>
<td>-1.393</td>
<td>0.164</td>
</tr>
</tbody>
</table>

It is important to bear in mind that although a lack of statistical significance was found, this may be influenced by the size of the two groups. It is possible that if the groups were to be increased in size, that statistical significance may be observed. Therefore, if the experiment was repeated with larger group sizes, a significant difference in ideation performance may be established, which may influence the results. Due to resource constraints and logical challenges in recruiting large numbers of students, it was not possible to test this within the scope of this study.

7.5.3 Influence of Mode on Self-efficacy

Table 34: Changes to students’ self-efficacy during the experiment. Ranges from 1 (strongly disagree) to 7 (strongly agree).

<table>
<thead>
<tr>
<th>Mode Used</th>
<th>N</th>
<th>Pre Self-Efficacy</th>
<th>Post Self-Efficacy</th>
<th>Change in Self-Efficacy</th>
<th>Z</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPG</td>
<td>22</td>
<td>5.50 (1.06)</td>
<td>5.23 (1.74)</td>
<td>-0.27</td>
<td>-0.749</td>
<td>0.454</td>
</tr>
<tr>
<td>CBG</td>
<td>26</td>
<td>5.35 (0.94)</td>
<td>4.88 (1.37)</td>
<td>-0.47</td>
<td>-1.803</td>
<td>0.071</td>
</tr>
</tbody>
</table>

Analysis of the results shown in Table 34 demonstrated that the self-efficacy of participants from each group slightly declined from the beginning to the conclusion of the creativity training session. The change in self-efficacy was calculated using pre self-efficacy as a baseline minus the post self-efficacy. On the 7-Point Likert Scale, the self-efficacy of PPG declined by 0.27 on average from a value of 5.50 to 5.23, while the self-efficacy of CBG declined 0.47 on average from 5.35 to 4.88. Results of the non-parametric Wilcoxon Signed
Ranks Test showed there were no significant differences between the pre and post self-efficacy of either group. This demonstrated that the self-efficacy of each group did not significantly change throughout the creativity training session.

In addition, the mean values for change in self-efficacy of PPG and CBG were also compared. This allowed observation of whether the decline in CBG’s self-efficacy was significantly larger than that of PPG, this would provide evidence that the mode used in creativity training may influence self-efficacy. Results of the Mann-Whitney U test of significance showed that the mean decline in self-efficacy between PPG and CBG was statistically insignificant.

**Table 35: Comparison of change in self-efficacy of PPG and CBG**

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
<th>Metric</th>
<th>Z</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPG</td>
<td>CBG</td>
<td>Change in Self-Efficacy</td>
<td>-0.615</td>
<td>0.538</td>
</tr>
</tbody>
</table>

**7.5.4 Student Interest in Creativity Training and Preference of Mode**

Analysis showed that PPG and CBG’s responses to the two questions in Table 36 were statistically insignificant for both questions. Therefore, the two groups were combined, showing the results presented in Table 36.

**Table 36: Student interest in creativity training and preference of mode**

<table>
<thead>
<tr>
<th>No.</th>
<th>Question</th>
<th>N</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>“I would like to have activities like this one available in the future, to assist in developing my problem solving skills.</td>
<td>48</td>
<td>4.42 (1.77)</td>
</tr>
<tr>
<td>2</td>
<td>“If activities like this one are made available in the future, I would prefer to use a web based interface to engage in the activity, rather than pen-and-paper.</td>
<td>48</td>
<td>4.48 (1.62)</td>
</tr>
</tbody>
</table>

Measured on 7-point Likert scale. 1- Strongly Disagree to 7-Strongly Agree.

Analysis showed that there were very weak, non significant correlations between students’ interest in creativity training (question 1 in Table 36) and the factors of fluency ($\rho=-0.09$), flexibility ($\rho=-0.14$), and change in self-efficacy ($\rho=-0.04$).

**7.5.5 Influence of Self-efficacy on Ideation Performance**

The review by Puente-Díaz (2016) identified that there was a positive link between creative self-efficacy and creative outcomes. As a result, an important part of this experiment was to establish whether this positive link between self-efficacy and creativity outcome was also observed in the context of this experiment.

As the ideation performance of PPG and CBG was equivalent, both groups were combined for the analysis. Due to the non-normal distributions of fluency and flexibility ($p<0.05$), correlation between the metrics was evaluated using the non-parametric Spearman’s rho correlation coefficient. As can be seen in Table 37, there were very small, positive, non-significant correlations between pre-experimental self-efficacy and the ideation performance metrics. This suggests that in contrast to the findings of Puente-Díaz (2016), the outcomes of
this study suggest that self-efficacy was not a strong predictor of creative outcome. In this case, it is possible that the experimental treatment may have influenced ideation performance more than self-efficacy.

Table 37: Correlation between pre-experimental self-efficacy and ideation metrics (PPG & CBG)

<table>
<thead>
<tr>
<th>First Metric</th>
<th>Second Metric</th>
<th>N</th>
<th>Spearman’s rho (Correlation coefficient)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Experimental Self-Efficacy</td>
<td>Fluency</td>
<td>48</td>
<td>0.133</td>
<td>0.367</td>
</tr>
<tr>
<td>Pre-Experimental Self-Efficacy</td>
<td>Flexibility</td>
<td>48</td>
<td>0.053</td>
<td>0.722</td>
</tr>
</tbody>
</table>

7.6 Discussion

7.6.1 Ideation Performance
The ideation performance of PPG and CBG can be seen in Table 32. While the performance of CBG may appear lower than PPG at first as PPG generated an average of 5.68 ideas compared to an average of 4.12 generated by CBG, and PPG used more fields of MATCEMIB to generate ideas than PBG (3.19 versus 2.64 of the six fields), analysis demonstrated that there was no significant difference in ideation performance between the two groups. Neither fluency nor flexibility was statistically significant between PPG and CBG. Therefore, any difference in self-efficacy between the groups cannot be directly attributed to the performance of each group. In addition, this outcome reinforces the findings of Experiment 1.

7.6.2 Self-efficacy
The results presented in this experiment provide evidence that in the context of creativity training and resolving a problem which requires the use of ideation and creativity, mode does not influence self-efficacy. The self-efficacy of neither group significantly changed during the creativity training session. In addition, the mean decline in self-efficacy was statistically insignificant between the groups. Considered together, these findings provide evidence that the mode which was used during the creativity training session did not influence participants’ self-efficacy to resolve the problem.

This finding suggests that using a computerised approach during creativity training will not negatively influence participants’ self-efficacy to generate ideas and resolve the problem, compared to if a traditional pen-and-paper approach is used. In other words, it is unlikely that use of a computer environment is in itself a detriment to students’ self-efficacy. This suggests that computerised creativity training activities are unlikely to have unintentional negative consequence on students’ learning outcomes in terms of developing self-efficacy. As previously stated, self efficacy is strongly and positively linked to performance (Puente-Díaz, 2016; Schunk, 1995) and motivation (Schunk, 1995). It is therefore essential that alternative learning environments or methods do not negatively influence self-efficacy compared to the existing method of completing the task. This also applies to the context of creativity training.
Reflecting upon the existing literature discussed in section 3.8, previous research has highlighted that within the context of completing assessment style tasks, using a computer-based approach can lead to positive influences on self-efficacy in comparison to if a pen-and-paper approach is used (Chua, 2012; Chua & Don, 2013; Nikou & Economides, 2016). The studies conducted by (Chua, 2012) and (Chua & Don, 2013) both found that the self-efficacy of paper-based test participants declined, while the self-efficacy of computer-based participants increased. (Nikou & Economides, 2016) also found that the self-efficacy of computer-based test participants increased, but self-efficacy of paper-based test participants remained the same in this instance. It is apparent that the results of this study do not neatly align with any of these existing studies. Instead, this study found that self-efficacy declined when using either mode, although the decline was statistically insignificant in each case.

However, it is required that the context is kept in mind. Each of these existing studies deals with a context other than creativity training. This study adds to the existing literature through empirical demonstration that the mode used during creativity training does not influence self-efficacy.

7.6.3 Student Interest in Creativity Training Activities
Reflection upon the results shown in Table 36 highlights two primary findings. First, it is apparent that engineering students show mild positive interest in the possibility of creativity training activities being adopted into engineering curricula. Students responded with a mean value of 4.42 on the 7-point Likert scale rating from 1 (strongly disagree) to 7 (strongly agree).

Previous research had demonstrated that engineering students place high value on the inclusion of creativity in engineering curricula (Waller & Strong, 2017) and consider that creativity is an important skill for professional engineers to possess (Wickramasinghe & Perera, 2010). Reflecting upon the results of a five day creativity workshop, Zhou (2012) established that most students thought that creativity training was useful, necessary, and that they may benefit from it. This study builds upon the findings of Zhou (2012), and demonstrates that short creativity training activities may be a suitable means for engineering educators to try and address the issue of building creativity skills, in a way that may be positively received by the majority of students.

If such activities are introduced in first year of study, this finding demonstrates that reception may not be extremely positive, but it is at least unlikely to be highly negative. Engagement in this activity was likely the first creativity training which many of the participants had been involved in. It is possible that students’ positive attitude towards creativity training activities may increase even more with each additional training session and they become more familiar and comfortable with the concept of learning creativity techniques.

7.6.4 Preference of Mode for Creativity Training Activities
The second finding demonstrates that engineering students show mild preference towards completing creativity training activities using a computer-based mode, as opposed to using a pen-and-paper mode. As discussed in section 3.9, previous research has primarily found that people prefer to complete tests and assessment items using a computer over pen-and-paper,
but prefer to read using print material instead of electronic books. Therefore, this finding aligns more with the literature investigating preference of mode in the context of completing a test or assessment item.

As discussed in section 3.9, students utilise electronic books a lot more than print books even though they actually prefer to read print material. Accessibility and convenience of electronic books outweighs student’s mode preference. Based upon this logic, it is reasonable to predict that students may engage with computer-based creativity training activities more than paper-based activities, simple because they are more accessible and convenient.

Therefore, this finding may suggest that efforts to computerise creativity training activities might increase students’ uptake and engagement rates with such tasks, both through increased motivation and ease of access.

Even though people do not necessarily perform more effectively at a task using their preferred mode of choice (see section 3.4.3), people may be more likely to at least engage with a task if it is presented to them in a manner which is most appealing to them. In the interest of enhancing students’ creativity skills through the use of either voluntary self-directed learning activities or activities embedded into engineering curricula, this adds credence to the idea that computerising creativity training activities may be worth designing and implementing in terms of cost, time and effort involved.

7.6.5 Limitations
Limitations of this experiment include the context under which the experiment took place. This may influence the generalisability of the findings.

This experiment was conducted using participants enrolled at an Australian tertiary institution, who were studying engineering programs in the discipline of electrical and computer engineering. There are numerous factors which may influence the results of this experiment, and whether the outcome may be repeatable or applicable at another tertiary institution. Such factors may include the specific tertiary institution, the country or region where the institution is located, the tertiary institution entry requirements, the year level and age of students (such as mature age students aged 22 or over), the level of previous engineering-related work experience, pre-existing creativity skills of students, and the computer and online familiarity of students.

Also of importance is that convenience sampling was used. Participants who bought their laptop to the tutorial classes were allocated to the appropriate CBG, while other participants were allocated to the appropriate PPG. However, to control for this, the pre-experiment questionnaire was utilised. Results showed that the groups were statistically insignificant on all metrics, meaning that they may be considered equivalent and suitable for comparison.

Nevertheless, it is possible that despite the response to the first question in Table 31, students who bought their laptops to the class may actually be more confident in the use of computers, which may influence the findings. The p-value for differences in performance between PPG
and CBG in Table 33 were around 0.15, and it is important to acknowledge that slight differences in the make-up of the two groups may influence the findings.

7.7 Summary and Recommendations

The outcomes of this experiment contribute valuable findings to the existing literature on creativity training activities within the context of engineering education.

1. The mode used to engage in creativity training activities does not influence a person’s self-efficacy to resolve the problem. Using a computer-based mode does not negatively influence self-efficacy compared to use of a pen-and-paper mode. Use of a computer-based mode influences self-efficacy in a similar manner to the way that use of pen-and-paper influences self-efficacy.

2. Engineering students showed slightly positive interest towards the notion of engaging in idea generation activities, with the aim of enhancing their problem-solving and creativity skills.

3. Engineering students demonstrated slight positive agreement that they would prefer to use a web based interface to engage in idea generation learning activities, rather than pen-and-paper.

Building upon the recommendations from experiments 1 and 2, this experiment has resulted in the following (expanded) recommendation for engineering educators who are looking for ways to increase the creativity of engineering students.

Developing online creativity training activities and making them widely available may be one way which the creativity skills of engineering students may be effectively built upon and enhanced throughout an engineering degree. Students may also be more willing and interested to engage in such activities if they are computer-based. It is evident that such activities can have long-term measurable benefits to students’ ideation performance, helping to overcome the issue of fixation. In addition, self-efficacy is not negatively influenced by the use of a computer-based mode during creativity training, meaning that students will build the confidence needed to face and resolve unfamiliar problems.
Chapter 8: Models of Influencing Factors in Creativity Heuristics Training
This Chapter will present two models which have been created based upon the findings on experiments 1-3, discussed in Chapters 5-7. The models visually reflect the recommendations discussed at the end of each Chapter.

8.1 Model of Factors Influencing Ideation Performance during Creativity Training
The proceeding discussion during Chapters 5-7 has highlighted how several factors present during creativity training may have an influence participants’ ideation performance. Experiment 1 demonstrated that the mode used to complete creativity training does not influence ideation performance, and that the template length also did not influence ideation performance. On the contrary, students’ year level and their enrolment status may influence the number of ideas which are generated, when considering the overall cohort and the average performance of the group. None of the factors investigated in Experiment 1 above were found to significantly influence students’ idea flexibility. In addition, it was found that there was a statistically significantly negative correlation between self-efficacy and idea fluency. The results of Experiment 2 demonstrated that mode does not influence self-efficacy during creativity training.

![Diagram of models showing the relationship between change in self-efficacy, mode, template length, year level, enrolment type, fluency, and flexibility.](image)

*Figure 17: Model of Factors Influencing Ideation during Creativity Training*

As a result of these findings, the model shown in Figure 17 is proposed as a reference which educators may refer to when considering the possibility of engaging engineering students in
creativity heuristics training activities. The model provides a visual representation of the factors which educators need to consider when designing and implementing creativity training activities into curricula, or making such activities available for students who wish to engage in self-directed learning.

### 8.1.1 Practical Implications

In summary, the model presented in Figure 17 demonstrates that the factors of year level and enrolment type are most important when designing and implementing creativity training activities into curricula.

Reflecting upon the recommendations made in Chapters 4, 5 and 7, such activities are likely to be more effective if introduced into first year of curriculum. Students in lower year levels are either more able, or willing, to engage in such learning activities, and are therefore more likely to demonstrate increased ideation performance. In turn, this is more likely to help students overcome the issue of fixation.

Findings of Experiment 1 also demonstrate that international students show lower ideation performance than local students. As discussed in Experiment 1 the cause for this is unclear, however, it is possible that many international students studied English as a second language which may influence their performance in some way. It is therefore possible that if creativity training activities are introduced to curricula, educators must bear in mind that international students may need more assistance or clarification during the activities in order to maximise their learning outcomes.

### 8.2 Model of Factors Influencing Long-term Ideation Performance after Creativity Training

As a result of the findings of Experiment 2, the model shown in Figure 18 is proposed when considering the long-term influence of engaging engineering students in creativity training activities.

![Figure 18: Model of Factors in Creativity Training Which Influence Long-Term Ideation Performance](image)

It was found that engaging students in creativity training lead to higher long-term idea fluency and flexibility. Therefore, Figure 18 shows that engaging students in creativity training
activities will influence these performance metrics. In addition, it was found that the mode used to engage in creativity heuristics training does not influence long-term ideation performance, while the length of the template that was originally used did influence long-term ideation performance.

8.2.1 Practical Implications
Figure 17 demonstrated that students were able to engage in creativity training activities using any mode, without negative influence on ideation performance. Figure 18 expands upon this finding through demonstration that the mode used in creativity training activities also does not influence development or retention of long-term ideation performance. Reflecting upon the recommendations made in Chapter 6, this provides educators with evidence that there is unlikely to be negative outcomes to ideation performance if students do use a computer to engage in the activity, rather than pen-and-paper. This adds strong credibility to the idea that certain creativity training activities can be computerised without negatively influencing appropriate learning outcomes. Practically, this implies that educators may seek to provide creativity training activities to students in either mode.

Figure 17 demonstrated that students were able to engage in creativity training activities using either the short or extended templates, without negative influence on ideation performance. However, Figure 18 highlights an important point. While the template length may not initially influence ideation performance during a creativity training activity, it may have measurable long-term effects on ideation performance. On average, using an extended template lead to lower ideation performance in the long-term, compared to if a short version of the template was used. Practically, educators need to be aware of any templates they may utilise, how they are designed, and how this may influence learning outcomes. While templates with a lot of guiding information may seem initially helpful, it may mean that participants cannot remember the key information as well in the long-term.
Chapter 9: Conclusion and Future Research

9.1 Conclusion
Within the engineering profession in Australian and New Zealand, there is an increasing demand for engineers who possess creativity skills who will be able to drive technological innovation into the future. In order for professional engineers to possess effective creativity and innovation skills, it is imperative that completing an accredited engineering degree actively works to enhance these skills. Engineering educators and curricula designers need properly evaluate engineering programs and course to ensure that they are designed in such a way that students’ creativity and problem-solving skills will be successfully enhanced throughout studying an engineering degree.

This thesis aimed to address two main issues regarding creativity within engineering education. The first was to quantify the coverage of creativity material within engineering curricula in Australia and New Zealand, to paint a clear picture of whether engineering education in these countries does sufficient work to successfully nurture students’ creativity skill. Analysis of over eleven hundred course outlines from forty-nine electrical engineering programs hosted by thirty-two tertiary institutions across Australia and New Zealand found that coverage of creativity-related material was overall very low. Only twenty-three courses were found to contain creativity-related material, and that the majority were restricted to the first year of engineering programs. As a result of this finding, it was recommended that Engineers Australia and Engineering New Zealand should adapt their criteria for assessing whether engineering programs foster creativity skills or not. In order for all engineering programs to build creativity skills, accredited engineering programs should require students to explicitly learn about creative theory and creativity techniques, as opposed to implicitly only through the completion of engineering design projects. In addition, it was recommended that engineering educators spend sufficient time to comprehend such updated requirements and appropriately integrate this into selected/nominated applicable courses which they teach.

The second point this thesis aimed to address the question of whether online creativity heuristics training activities may be a suitable way for engineering educators to provide opportunities to students to work on building their creativity skills, either through integration into engineering curricula or self-directed study, with the specific focus of helping students to overcome the common issue of idea fixation. Three experiments were conducted using a primarily quantitative research design to investigate the potential suitability of this alternative learning method. Metrics including ideation performance and self-efficacy were compared between groups of students who used a traditional pen-and-paper approach, to groups of students who used an equivalent computerised approach. Results demonstrated no observable mode-effect based upon either ideation performance or self-efficacy, while students showed interest in creativity heuristics training activities and reported that they preferred to complete such activities using a computerised platform. In addition, creativity heuristics training showed a measureable longitudinal benefit to ideation performance, and that the mode initially used during creativity training did not influence longitudinal ideation performance.
Considered together, these findings demonstrated that from an educator’s point of view, developing online creativity training activities and making them widely available may be one way which the creativity and problem-solving skills of engineering students may be effectively built upon and enhanced throughout an engineering degree. This is especially the case where a host institution otherwise has a lack of creativity related material throughout their engineering curricula. Making creativity training available in students’ first year of study is ideal as first-year students may be more willing to engage with the activity, and it provides more time throughout their degree when they can practice and make use of the training.

9.2 Future research

Future research may seek to enhance the generalisability of the findings of this study by introducing the use of random sampling. Due to resource and feasibility constraints, convenience sampling was utilised in experiments 1 and 3. Although care has been taken to ensure that the groups may be considered equivalent were required, but a more ideal approach would be to use random sampling.

An important limitation of this thesis is that it primarily focuses on creativity training activities which may help students to overcome the problem of fixation during creative problem-solving. As a result, the scope of the thesis has been limited to analysing whether there is an observable mode effect on creativity training activities which focus specifically on idea generation. Although idea generation may be widely synonymous with creativity, creativity is a process which involves many stages.

Reflecting upon the discussion of section 3.6.4, the framework set out by Wang and Nickerson (2017) advocates that creativity support systems should not only focus on idea generation, but include means to help users through all stages of the creative process. Future research may aim to build upon this work by expanding the scope to investigate whether there are observable mode effects within other stages or components of the overall creative problem-solving process. For example, Harlim and Belski (2017) argue that understanding the problem is a key stage of the problem solving process which engineering educators should focus on to develop the problem solving skills of engineers.

Reflecting upon the four ways in which software can assist in the creative process, the software for this study was designed to work as a coach, acting as an “expert system, knowledgeable in creativity-relevant techniques” (Lubart, 2005). Reflecting on the other ways in which a software can assist in the creative process (nanny, pen-pal, colleague), it is apparent that pen-and-paper cannot be designed to fulfil all of these roles. A pen-and-paper system in itself cannot physically act as a nanny or a colleague in the way that a computer system can. Therefore, it is not really feasible to study whether there is an observable mode-effect when software is designed to fulfil these roles. On the other hand, research has already investigated possible mode-effects in the situation of software working as a pen-pal, through the comparison of groups using brainwriting versus groups using electronic brainstorming.

Considering the four ways that a computer can assist in educational measurement (computerised testing, computer adaptive testing, continuous measurement, intelligent
measurement) Bunderson et al. (1988), the software designed for this study was analogous to the case of computerised testing, as the method of interaction is one way. The user can interact with the software, but the software cannot interact with the user. Educators may seek to build upon the findings of this study by engaging students in numerous computerised creativity training activities as part of a course focused on creativity. In this case, it is possible that the computer system may monitor student progress over the course potentially assessing work (i.e. continuous measurement), and encouraging students to work on creativity skills where they perform less effectively (i.e. computer adaptive testing). Such future research on the adoption of such computerised creativity training would provide important insights into the expanded possibilities of computerised creativity training. Not only demonstrating that certain creativity focused learning activities can be adapted to a computerised system without detriment to learning outcomes, but also building upon this by investigating how such software may include addition features, and whether such features can be empirically demonstrated to enhance student learning.
Appendix A: Ethics Approval

RMIT UNIVERSITY

2nd July 2015

Iouri Belski
Building 10 Level 10, Room 1
School of Electrical and Computer Engineering
RMIT University

Dear Iouri

BSEHAPP 19-15 BELSKI-VALENTINE Investigating the influence of web-based problem-solving tools on the problem-solving performance of engineering students

Thank you for submitting your amended application for review.

I am pleased to inform you that the CHEAN has approved your application for a period of 3 Years from the date of this letter to 2nd July 2018 and your research may now proceed.

The CHEAN would like to remind you that:

All data should be stored on University Network systems. These systems provide high levels of manageable security and data integrity, can provide secure remote access, are backed up on a regular basis and can provide Disaster Recover processes should a large scale incident occur. The use of portable devices such as CDs and memory sticks is valid for archiving, data transport where necessary and for some works in progress.

The authoritative copy of all current data should reside on appropriate network systems; and the Principal Investigator is responsible for the retention and storage of the original data pertaining to the project for a minimum period of five years.

Please Note: Annual reports are due on the anniversary of the commencement date for all research projects that have been approved by the CHEAN. Ongoing approval is conditional upon the submission of annual reports failure to provide an annual report may result in Ethics approval being withdrawn.

Final reports are due within six months of the project expiring or as soon as possible after your research project has concluded.

The annual/final reports forms can be found at: www.rmit.edu.au/staff/research/human-research-office

Yours faithfully,

Dr Falk Scholer
Deputy Chair, Science Engineering & Health
College Human Ethics Advisory Network

Cc CHEAN Member: Yan Wang School of Mathematical and Geospatial Sciences RMIT University
   Student Investigator: Andrew Valentino School of Electrical and Computer Engineering RMIT University
   Other Investigator: Margaret Hamilton School of Computer Science and Information Technology
## Appendix B: Review of the Influence of Mode on Test and Assessment Task Performance

### Table 38: Review of the Influence of Mode on Test and Assessment Task Performance

<table>
<thead>
<tr>
<th>Study</th>
<th>Group and Assessment Task (Context)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provides Evidence Paper-Based &gt; Computer-Based</strong></td>
<td></td>
</tr>
<tr>
<td>Bennett et al. (2008)</td>
<td>Secondary School Students ‘Math Online (MOL)’ Mathematics Test</td>
</tr>
<tr>
<td>Emerson and MacKay (2011)</td>
<td>Undergraduate Students Study Programme of Several Lessons. Influence on Test Performance at End.</td>
</tr>
<tr>
<td>Flowers et al. (2011)</td>
<td>School Students (Years 7-8) With Disabilities Assessments consisted of multiple-choice and constructed-response items. Students used read-aloud (oral) presentation.</td>
</tr>
<tr>
<td>Nikoopour et al. (2013)</td>
<td>Undergraduate English as a Foreign Language Students ‘Objective Placement Test’</td>
</tr>
<tr>
<td>Patel, Amanullah, Mohanna, and Afaq (2014)</td>
<td>Undergraduate Medical Students Multiple-Choice Exam</td>
</tr>
<tr>
<td>Jeong (2014)</td>
<td>Secondary School Students Multiple-Choice Test</td>
</tr>
<tr>
<td>Marcenaro-Gutiérrez and López-Agudo (2016)</td>
<td>School Students ‘Program for International Student Assessment (PISA)’</td>
</tr>
<tr>
<td><strong>Provides Evidence Paper-Based = Computer-Based</strong></td>
<td></td>
</tr>
<tr>
<td>Lloyd et al. (1996)</td>
<td>Undergraduate Engineering Students</td>
</tr>
<tr>
<td>Campton (2004)</td>
<td>Undergraduate Business Students Multiple-Choice Test</td>
</tr>
<tr>
<td>Özlapt-Yaman and Çağiltay (2010) &amp; Cagiltay and Ozlap-Yaman (2013)</td>
<td>Undergraduate Engineering Students Multiple-Choice Exam (Both studies use the same data)</td>
</tr>
<tr>
<td>Hochlehnert, Brass, Moeltner, and Juenger (2011)</td>
<td>Fifth Year Medical Students Multiple-Choice &amp; Short Answer Test</td>
</tr>
<tr>
<td>Macrander, Manansala, Rawson, and Han (2012)</td>
<td>Undergraduate Students ‘Graduate Record Examinations (GRE)’ Verbal Test</td>
</tr>
<tr>
<td>Nikou and Economides (2013)</td>
<td>Undergraduate Economics Students Multiple-Choice Test</td>
</tr>
<tr>
<td>Tsai and Shin (2013)</td>
<td>Dental Students National Board Dental Hygiene Examination</td>
</tr>
<tr>
<td>Jeong (2014)</td>
<td>School Students Multiple-Choice Tests</td>
</tr>
<tr>
<td>Meyer, Innes, Stomski, and Armson (2016)</td>
<td>Undergraduate Anatomy Students Gross Anatomy Examination</td>
</tr>
<tr>
<td>Delen (2015)</td>
<td>Undergraduate Primary Education Students Multiple Choice Test</td>
</tr>
<tr>
<td>Khoshsima et al. (2017)</td>
<td>Undergraduate English as a Foreign Language Students ‘Vocabulary in Use’ Test</td>
</tr>
<tr>
<td>Prisacari and Danielson (2017)</td>
<td>Undergraduate Chemistry Students Three Tests During a Course</td>
</tr>
<tr>
<td>Lappalainen, Lakanen, and</td>
<td>Undergraduate Computer Science Students</td>
</tr>
</tbody>
</table>

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### Appendix B: Review of the Influence of Mode on Test and Assessment Task Performance

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Task Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Högmander (2017)</td>
<td>Final Exams (Two Cohorts)</td>
</tr>
<tr>
<td>Prisacari, Holme, and Danielson (2017)</td>
<td>Undergraduate Chemistry Students Finals Exams (multiple-choice and open-ended format)</td>
</tr>
</tbody>
</table>

**Provides Evidence Computer-Based > Paper-Based**

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Task Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gretes and Green (2000)</td>
<td>Undergraduate Education Students Practice Tests</td>
</tr>
<tr>
<td>Clariana and Wallace (2002)</td>
<td>Undergraduate Business Students Test Assessment</td>
</tr>
<tr>
<td>Bonham, Deardorff, and Beichner (2003)</td>
<td>Undergraduate Physics Students Homework Tests (Multiple-Choice &amp; Short Answer)</td>
</tr>
<tr>
<td>Coniam (2006)</td>
<td>Secondary School Students English Language Listening Test</td>
</tr>
<tr>
<td>Lenz (2010)</td>
<td>Undergraduate Mathematics Students Homework Performance</td>
</tr>
<tr>
<td>Gok (2011)</td>
<td>Undergraduate Physics Students Homework Performance (14 weeks, 10 questions per week)</td>
</tr>
<tr>
<td>Wilson, Boyd, Chen, and Jamal (2011)</td>
<td>Undergraduate Geography Students Multiple-Choice Practice Tests, Influence on Final Exam</td>
</tr>
<tr>
<td>Tsuei (2013)</td>
<td>Elementary School Students (Year 3) Mathematics Tests</td>
</tr>
<tr>
<td>Khoshchina and Toroujeni (2017)</td>
<td>Graduate University Students ‘New-Interchange Placement Test’</td>
</tr>
<tr>
<td>Washburn et al. (2017)</td>
<td>Undergraduate Veterinary Students Multiple-Choice Test</td>
</tr>
</tbody>
</table>

**Provides Other Evidence**

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Task Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nikou and Economides (2016)</td>
<td>Undergraduate Physics Students Multiple-Choice Quizzes “Low- and medium-achieving students benefit more from computer- and mobile-based self-assessments”</td>
</tr>
</tbody>
</table>
### Appendix C: Review of the Influence of Mode on Reading Comprehension

**Table 39: Review of the Influence of Mode on Reading Comprehension**

<table>
<thead>
<tr>
<th>Study</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provides Evidence Paper-Based &gt; Computer-Based</strong></td>
<td></td>
</tr>
<tr>
<td>Pomplun, Frey, and Becker (2002)</td>
<td>High School, Undergraduate Students</td>
</tr>
<tr>
<td>Kerr and Symons (2006)</td>
<td>School Students (Year 5)</td>
</tr>
<tr>
<td>Jeong (2012)</td>
<td>School Students (Year 6)</td>
</tr>
<tr>
<td>Ackerman and Lauterman (2012)</td>
<td>Undergraduate Social Science and Humanities Students</td>
</tr>
<tr>
<td>El-Mouelhy, Poon, Hui, and Sue-Chan (2013)</td>
<td>School Students (Year 1, 4, 6)</td>
</tr>
<tr>
<td>Stoop et al. (2013)</td>
<td>School Students (Year 10)</td>
</tr>
<tr>
<td>Mangen, Walgermo, and Brønnick (2013)</td>
<td>School Students (Age 20-23)</td>
</tr>
<tr>
<td>Chen et al. (2014)</td>
<td>Undergraduate Teaching (Education) Students</td>
</tr>
<tr>
<td>Mangen and Kuiken (2014)</td>
<td>Students</td>
</tr>
<tr>
<td>Neijens and Voorveld (2016)</td>
<td>Students</td>
</tr>
<tr>
<td><strong>Provides Evidence Paper-Based = Computer-Based</strong></td>
<td></td>
</tr>
<tr>
<td>Korat and Shamir (2007)</td>
<td>Kindergarten Children (Aged 5-6)</td>
</tr>
<tr>
<td>Connell et al. (2012)</td>
<td>School Students (Year 5)</td>
</tr>
<tr>
<td>Dundar and Akcayir (2012)</td>
<td>School Students (Year 5)</td>
</tr>
<tr>
<td>Wells (2012)</td>
<td>Middle and High School English students</td>
</tr>
<tr>
<td>Margolin, Driscoll, Toland, and Kegler (2013)</td>
<td>Undergraduate Psychology Students Participants Aged 18-25</td>
</tr>
<tr>
<td>Daniel and Woody (2013)</td>
<td>University Psychology Students</td>
</tr>
<tr>
<td>Sun, Shieh, and Huang (2013)</td>
<td>Participants Aged 45-54</td>
</tr>
<tr>
<td>Young (2014)</td>
<td>University Students</td>
</tr>
<tr>
<td>Seehafer (2014)</td>
<td>Undergraduate Psychology Students</td>
</tr>
<tr>
<td>Chen and Catrambone (2015)</td>
<td>School Students (Year 9, 10)</td>
</tr>
<tr>
<td>Porion, Aparicio, Megalakaki, Robert, and Baccino (2016)</td>
<td>School Students (Year 9, 10)</td>
</tr>
<tr>
<td>Hermena et al. (2017)</td>
<td>Undergraduate Students (Native Arabic Speakers) Reading Comprehension (Arabic Language)</td>
</tr>
<tr>
<td>Hou et al. (2017)</td>
<td>Undergraduate Communication Students</td>
</tr>
<tr>
<td>Singer and Alexander (2017)</td>
<td>Undergraduate Students</td>
</tr>
<tr>
<td><strong>Provides Evidence Computer-Based &gt; Paper-Based</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>There is a lack of studies in the literature which meet this criterion.</td>
</tr>
</tbody>
</table>
## Appendix D: Review of the Influence of Mode on Creativity and Ideation Performance

### Table 40: Review of the Influence of Mode on Group Creativity and Ideation Performance

<table>
<thead>
<tr>
<th>Study</th>
<th>Group and Task (Context)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Provides Evidence Non-Computer-Based &gt; Computer-Based</strong></td>
<td></td>
</tr>
<tr>
<td>Kohn et al. (2011)</td>
<td>Compared the effects of EBS and NBS on idea combination. NBS was more effective than EBS.</td>
</tr>
<tr>
<td><strong>Provides Evidence Non-Computer-Based = Computer-Based</strong></td>
<td></td>
</tr>
<tr>
<td>Barki and Pinsonneault (2001)</td>
<td>Compared idea quality of small groups using EBS, VBS and NBS. NBS group performed at least as well as EBS group.</td>
</tr>
<tr>
<td><strong>Provides Evidence Computer-Based &gt; Non-Computer-Based</strong></td>
<td></td>
</tr>
<tr>
<td>Valacich, Dennis, and Connolly (1994)</td>
<td>Large computer-based groups outperformed equivalent nominal groups engaged in idea generation tasks.</td>
</tr>
<tr>
<td>Dennis and Valacich (1994)</td>
<td>EBS group outperformed NBS group. EBS group produced more ideas, and ideas were higher quality.</td>
</tr>
<tr>
<td>Pinsonneault et al. (1999)</td>
<td>EBS and electronic-NBS groups outperformed VBS group.</td>
</tr>
<tr>
<td>Kerr and Murthy (2004)</td>
<td>Compared the effectiveness of computer-mediated and face-to-face groups on divergent and convergent idea generation. Computer-mediated was most effective for divergent. Face-to-face was most effective for convergent.</td>
</tr>
<tr>
<td>Forgionne and Newman (2007)</td>
<td>Enhanced computer-based Decision Support System versus two conditions (1) basic computer-based Decision Support System and (2) no software or guidance. Enhanced computer-based Decision Support System outperformed both other groups.</td>
</tr>
<tr>
<td>DeRosa et al. (2007)</td>
<td><strong>Meta-analysis</strong> of EBS groups versus traditional face-to-face (FTF) interacting groups. EBS is generally more effective.</td>
</tr>
<tr>
<td>Lynch et al. (2009)</td>
<td>EBS more effective than traditional VBS.</td>
</tr>
<tr>
<td>Michinov (2012)</td>
<td>Comparison of EBS and Brainwriting (6-3-5 brainstorming).</td>
</tr>
<tr>
<td><strong>Provides Other Evidence (e.g. Multiple Results, or Results Vary)</strong></td>
<td></td>
</tr>
<tr>
<td>Gallupe et al. (1992)</td>
<td>Comparison of EBS and VBS. Performance between EBS and VBS was similar in small groups. EBS increased performance in large groups.</td>
</tr>
<tr>
<td>Dennis and Valacich (1993)</td>
<td>Comparison of EBS and VBS. Performance between EBS and VBS was the same in smaller groups. EBS increased performance in large groups.</td>
</tr>
<tr>
<td>Cooper, Gallupe, Pollard, and Cadsby (1998)</td>
<td>Compared anonymous EBS, non-anonymous EBS, NBS, and VBS. Anonymous EBS performed the same as NBS. NBS performed more effectively than non-anonymous EBS. Anonymous EBS outperformed VBS. Non-anonymous EBS outperformed VBS.</td>
</tr>
<tr>
<td>Author(s) and Year</td>
<td>Findings</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------</td>
</tr>
<tr>
<td>Dennis and Valacich (1999)</td>
<td>Concluded that previous research shows any gains between EBS and VBS in small groups is an illusion. Concluded that EBS is more effective than NBS and VBS in large groups.</td>
</tr>
<tr>
<td>Ziegler, Diehl, and Zijlstra (2000)</td>
<td>Compared EBS and NBS groups. EBS groups generated variety of ideas; more NBS were considered redundant. No difference between idea quality for EBS and NBS.</td>
</tr>
<tr>
<td>Hender, Dean, Rodgers, and Nunamaker Jr (2002)</td>
<td>Compared groups using EBS to use of face-to-face ideation techniques (Assumption Reversals and Analogies). Findings were mixed. EBS produced higher creativity than Assumption Reversals technique, but the same quantity of ideas. EBS resulted in the same creativity as Analogies technique, but produced a greater quantity of ideas.</td>
</tr>
<tr>
<td>Dennis and Williams (2005)</td>
<td><strong>Meta-analysis</strong> comparing EBS to VBS and EBS to NBS in various groups sizes. EBS is generally more effective in larger groups. EBS groups generally outperform VBS groups (but not always). Findings comparing EBS and VBS have mixed results.</td>
</tr>
</tbody>
</table>

Note: EBS=Electronic Brainstorming. VBS=Verbal Brainstorming. NBS=Nominal Brainstorming. VBS is the same as ‘traditional’ brainstorming.
Appendix D: Review of the Influence of Mode on Creativity and Ideation Performance

Table 41: Review of the Influence of Software on Individual Creativity and Ideation Performance, Compared to Control using No Software

<table>
<thead>
<tr>
<th>Study</th>
<th>Group and Task (Context)</th>
<th>Provides Evidence Software Usage Decreased Creativity, Compared To When No Software Was Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durand and VanHuss (1992)</td>
<td>Computer-based Decision Support System versus no software. Groups not provided any suggested process or technique to use. Use of DSS decreased creativity over no software.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study</th>
<th>Group and Task (Context)</th>
<th>Provides Evidence Software Usage Enhanced Creativity, Compared To When No Software Was Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elam and Mead (1990)</td>
<td>Computer-based Decision Support System versus no software. Groups not provided any suggested process or technique to use. Use of DSS increased creativity over no software.</td>
<td></td>
</tr>
<tr>
<td>Massetti (1996)</td>
<td>Individual Creativity Support Software versus no software. Use of ICCS increased creativity over no software.</td>
<td></td>
</tr>
<tr>
<td>Marakas and Elam (1997)</td>
<td>Computer-based Decision Support System versus no software. In comparison 1, groups were not provided any suggested process or technique to use. Use of DSS increased creativity over no software when the process was provided, and when it was not.</td>
<td></td>
</tr>
</tbody>
</table>

Table 42: Review of the Influence of Software on Individual Creativity and Ideation Performance, Compared to using a ‘Control’ Software (e.g. word processor)

<table>
<thead>
<tr>
<th>Study</th>
<th>Group and Task (Context)</th>
<th>Provides Evidence Software Usage Decreased Creativity, Compared To When Using Control Software</th>
</tr>
</thead>
</table>
Appendix E: Review of the Influence of Mode on Miscellaneous Tasks

Table 43: Review of the Influence of Mode on Miscellaneous Tasks

<table>
<thead>
<tr>
<th>Study</th>
<th>Group and Task (Context)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robinson and Brewer (2016)</td>
<td></td>
</tr>
<tr>
<td>Bailey et al. (2017)</td>
<td></td>
</tr>
</tbody>
</table>
### Appendix F: Evaluated Accredited Engineering Programs

#### F.1 Accredited by Engineers Australia

<table>
<thead>
<tr>
<th>University</th>
<th>Program Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Queensland University</td>
<td>Bachelor of Engineering (Honours) (Electrical)</td>
</tr>
<tr>
<td>Charles Darwin University</td>
<td>Bachelor of Engineering Honours (Electrical and Electronics Engineering)</td>
</tr>
<tr>
<td>Curtin University of Technology</td>
<td>Bachelor of Engineering (Honours) (Electrical Power Engineering)</td>
</tr>
<tr>
<td>Deakin University</td>
<td>Bachelor of Electrical and Electronic Engineering (Honours)</td>
</tr>
<tr>
<td>Edith Cowan University</td>
<td>Bachelor of Engineering (Electrical Power Engineering) Honours</td>
</tr>
<tr>
<td>Flinders University</td>
<td>Bachelor of Engineering (Electrical) (Honours)</td>
</tr>
<tr>
<td>Griffith University</td>
<td>Bachelor of Engineering (Honours) in Electrical and Electronic Engineering</td>
</tr>
<tr>
<td>James Cook University</td>
<td>Bachelor of Engineering (Honours) (Electrical and Electronic)</td>
</tr>
<tr>
<td>Monash University</td>
<td>Bachelor of Engineering (Honours) in Electrical and Computer Systems Engineering</td>
</tr>
<tr>
<td>Murdoch University</td>
<td>Bachelor of Engineering Honours (BE(Hons)) in Electrical Power Engineering</td>
</tr>
<tr>
<td>Queensland University of Technology</td>
<td>Bachelor of Engineering (Honours) (Electrical)</td>
</tr>
<tr>
<td>Queensland University of Technology</td>
<td>Bachelor of Engineering (Honours) (Electrical and Aerospace)</td>
</tr>
<tr>
<td>RMIT University</td>
<td>Bachelor of Engineering (Electrical and Electronic Engineering) (Honours)</td>
</tr>
<tr>
<td>RMIT University</td>
<td>Bachelor of Engineering (Electrical Engineering) (Honours)</td>
</tr>
<tr>
<td>Swinburne University of Technology</td>
<td>Bachelor of Engineering (Electrical and Electronic) (Honours)</td>
</tr>
<tr>
<td>The University of Adelaide</td>
<td>Bachelor of Engineering (Honours) (Electrical and Electronic)</td>
</tr>
<tr>
<td>The University of Adelaide</td>
<td>Bachelor of Engineering (Honours) (Electrical and Sustainable Energy)</td>
</tr>
<tr>
<td>The University of New South Wales</td>
<td>Bachelor of Engineering (Honours) (Electrical Engineering)</td>
</tr>
<tr>
<td>The University of Newcastle</td>
<td>Bachelor of Engineering (Honours) (Electrical)</td>
</tr>
<tr>
<td>The University of Queensland</td>
<td>Bachelor of Engineering (Honours) (Electrical Engineering)</td>
</tr>
<tr>
<td>The University of Queensland</td>
<td>Bachelor of Engineering (Honours) (Electrical and Biomedical Engineering)</td>
</tr>
<tr>
<td>The University of Queensland</td>
<td>Bachelor of Engineering (Honours) (Electrical and Computer Engineering)</td>
</tr>
<tr>
<td>University of South Australia</td>
<td>Bachelor of Engineering (Honours) (Electrical and Electronic)</td>
</tr>
<tr>
<td>University of South Australia</td>
<td>Bachelor of Engineering (Honours) (Electrical and Mechatronic)</td>
</tr>
<tr>
<td>University of Southern Queensland</td>
<td>Bachelor of Engineering (Honours) (Electrical and Electronic Engineering)</td>
</tr>
<tr>
<td>The University of Sydney</td>
<td>Bachelor of Engineering Honours (Electrical) (Telecommunications)</td>
</tr>
<tr>
<td>University of Technology Sydney</td>
<td>Bachelor of Engineering (Electrical Power Engineering) (Honours)</td>
</tr>
<tr>
<td>Western University Sydney</td>
<td>Bachelor of Engineering (Electrical Engineering)</td>
</tr>
<tr>
<td>Western University Sydney</td>
<td>Bachelor of Engineering Advanced (Honours) (Electrical)</td>
</tr>
<tr>
<td>University of Wollongong</td>
<td>Bachelor of Engineering (Honours) (Electrical Engineering)</td>
</tr>
<tr>
<td>Victoria University</td>
<td>Bachelor of Engineering (Electrical and Electronic Engineering) (Honours)</td>
</tr>
<tr>
<td>Victoria University</td>
<td>Bachelor of Engineering (Electrical and Sports Engineering) (Honours)</td>
</tr>
</tbody>
</table>
### F.2 Accredited by Engineering New Zealand

<table>
<thead>
<tr>
<th>University</th>
<th>Program Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUT University</td>
<td>Bachelor of Engineering (Honours) in Electrical and Electronic Engineering</td>
</tr>
<tr>
<td>Massey University</td>
<td>Bachelor of Engineering with Honours (Electronics and Computer Engineering)</td>
</tr>
<tr>
<td>University of Auckland</td>
<td>Bachelor of Engineering (Honours) in Electrical and Electronic Engineering</td>
</tr>
<tr>
<td>University of Canterbury</td>
<td>Bachelor of Engineering with Honours in Electrical and Electronic</td>
</tr>
<tr>
<td>University of the South Pacific</td>
<td>Bachelor of Engineering (Electrical and Electronic Engineering)</td>
</tr>
<tr>
<td>University of Waikato</td>
<td>Bachelor of Engineering with Honours in Electronic Engineering</td>
</tr>
<tr>
<td>Victoria University of Wellington</td>
<td>Bachelor of Engineering with Honours (Electronic and Computer Systems Engineering)</td>
</tr>
</tbody>
</table>
Appendix G: Experiment 1 Creativity Training Templates

G.1 Pen-and-paper Extended Template

Step 1) State the **required outcome** (what would you like to happen with the Barnacles. Please write over the grey letters “Required outcome” below):

```
  Barnacle 
  
  Required outcome
```

Step 2) Complete the written form of model solution proposed by the following triad:

```
  Barnacle 
  
  Influences 
  
  red 
  
  Produces 
  
  Required outcome
```

*I am looking for some new Field, which influences the Barnacle in such a way that the (enter the required outcome) is achieved.*

Step 3) Transform the model solution into ideas using fields of MATCEMIB. Write down your ideas:

**Mechanical field**

- Gravitational or gravity force.
- Interactions and phenomena associates with direct contact e.g. collisions.
- Vibration, resonance, shocks, waves (excluding acoustic waves).
- Phenomena related to gas and fluid dynamics, wind, pressure, compression, vacuum.
- Acts and events of mechanical treatment and processing: machining, drilling, land cultivation, etc.
- Interactions linked to deformation, mixing, additives (without chemical reactions), insertion, extraction, removal, attachment, etc.
Appendix G: Experiment 1 Creativity Training Templates

**Acoustic field**
- Audible sound, ultrasound, infrasound, noise.
- Sound transmission and reflection, resonance and standing waves, cavitation.

**Thermal field**
- Heating and cooling in general. Endothermic and exothermic reactions (including chemical and nuclear).
- Heat radiation, convection, heat conduction, heat insulation.
- Phase/state change (melting, boiling, and their opposites, solidification and condensation; sublimation), thermal expansion.
- Utilisation of fire, burning, heat treatment.

**Chemical field**
- Variety of chemical reactions, reactants, elements and compounds.
- Usage of catalysis, inhibitors, indicators.
- Processes of dissolving, crystallisation and polymerisation.
- Interactions related to changes in odour, taste, change in colour, pH, etc.
- Phenomena like chemiluminescence, chemisorption, chemical equilibrium, etc.
Appendix G: Experiment 1 Creativity Training Templates

**Electric field**
- Phenomena related to electrostatic charges, conductors and insulators.
- Ionisation, electrical discharge, electric arc, sparks.
- Behaviour of charges in electric field, electric current.
- Various phenomena like superconductivity, electrolysis, piezo-electrics, etc.

**Magnetic field**
- Magnetic field, magnetic forces and magnetic particles, magnetic induction.
- Electromagnetic field, electromagnetic waves (radio waves, microwaves infrared and ultraviolet radiation, X-rays, gamma rays, etc.).
- Visible range of electromagnetic spectrum (light) and effects associated with it including optics, vision, image, colour/translucence change, etc.

**Intermolecular field**
- Phenomena related on the weak nuclear force and the strong nuclear force, subatomic (nano-) particles.
- Acts and events associated with nuclear reactions, radiation (X-rays), fusion, emission, laser.
- Surface effects, evaporation, capillary effect and behaviour of porous bodies.
**Biological field**

- *Acts and events linked to the variety of the Earth’s fish, animal, plant and microbial species.*

- *Effects related to behaviours and structures of microbes, bacteria, viruses, living organisms, plants, fungi, cells, enzymes, etc.*

- *Biological phenomena like biosynthesis, genetic coding, cell division (mitosis or meiosis), cell differentiation, etc.*
G.2 Computer-based Extended Template

Some Questions First

1. I am a student from:
   - International
   - Australia
   - ATAR: [ ]

2. I am attending this tutorial.
   - Monday 08:30-09:30

3. I am using this type of device to access this web tool:
   - Desktop Computer
   - Laptop
   - Tablet With Keyboard
   - Handheld Tablet
   - Other

4. I always study using paper/printed materials (textbooks, printed lecture notes etc.).
   - Strongly Disagree
   - Disagree
   - Slightly Disagree
   - Not Sure
   - Slightly Agree
   - Agree
   - Strongly Agree
   - Add Comment

5. I always study using electronic materials (computer, e-books etc.).
   - Strongly Disagree
   - Disagree
   - Slightly Disagree
   - Not Sure
   - Slightly Agree
   - Agree
   - Strongly Agree
   - Add Comment

[Begin Using the Tool]

Setup the Problem

Step 1: What is name of the object you are trying to effect? [Barnacles]

What is the required outcome? [remove barnacles from the ship]

Step 2: The graphical model solution proposed by Rule 1 is sketched below (updates automatically):

[Diagram]

Written Model Solution (updates automatically):

I am looking for some new Field, which influences the Barnacles in such a way that remove barnacles from the ship is achieved.

[Restore]

[Back to Questions] [Next to Generate Ideas]
Generate Ideas

Step 3: Write down your ideas to solve the problem using fields of MATCEMIB:

I am looking for some new Field, which influences the Barnacles in such a way that remove barnacles from the ship is achieved.

- [ ] Mechanical
- [ ] Acoustic
- [ ] Thermal
- [ ] Chemical
- [ ] Electric
- [ ] Magnetic
- [ ] Intermolecular
- [ ] Biological

**Mechanical Field**

Gravitational or gravity force.

Interactions and phenomena associated with direct contact e.g., collisions.

Hit the barnacles with a hammer so they fall off.

Vibration, resonance, shocks, waves (excluding acoustic waves).

Phenomena related to gas and fluid dynamics, wind, pressure, compression, vacuum.

Acts and events of mechanical treatment and processing: machining, drilling, land cultivation, etc.

Interactions linked to deformation, mixing, additives (without chemical reactions), insertion, extraction, removal, attachment, etc.

Explosion (considered not as a process per se, but rather as a way to change/alter substances by means of explosion).

[Back to Setup the Problem] [Next to Review Ideas]
Appendix G: Experiment 1 Creativity Training Templates

Generate Ideas

Step 3: Write down your ideas to solve the problem using fields of MATCEMIB:

I am looking for some new Field, which influences the Barnacles in such a way that remove barnacles from the ship is achieved.

- Mechanical
- Acoustic
- Thermal
- Chemical
- Electric
- Magnetic
- Intermolecular
- Biological

Chemical Field

Variety of chemical reactions, reactants, elements and compounds.
Pour acid on the barnacles so that they dissolve and detach from the ship.

Usage of catalysts, inhibitors, indicators.

Process of dissolving, crystallisation and polymerisation.

Interactions related to changes in odour, taste, change in colour, pH, etc.

Phenomena like chemiluminescence, chemisorption, chemical equilibrium, etc.

Review Ideas

I am looking for some new Field, which influences the Barnacles in such a way that remove barnacles from the ship is achieved.

Hit the barnacles with a hammer so they fall off.
Pour acid on the barnacles so that they dissolve and detach from the ship.
Find a predator which will eat the barnacles, thus removing them from the ship.
Appendix G: Experiment 1 Creativity Training Templates

G.3  
Pen-and-paper Short Template

Step 1) State the **required outcome** (what would you like to happen with the Barnacles. Please write over the grey letters “Required outcome” below):

![Diagram of Barnacle and required outcome]

Step 2) Complete the written form of model solution proposed by the following triad:

![Diagram of problem, influence, and field]

*I am looking for some new Field, which influences the Barnacle in such a way that the (enter the required outcome) is achieved.*

Step 3) Transform the model solution into ideas using fields of MATCEMIB. Write down your ideas on the next page:

<table>
<thead>
<tr>
<th>Fields</th>
<th>Some Interactions and Substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Gravitation, collisions, friction, direct contact, vibration, resonance, shocks, waves, gas/fluid dynamics, wind, compression, vacuum, mechanical treatment and processing, deformation, mixing, additives, explosion.</td>
</tr>
<tr>
<td>Acoustic</td>
<td>Sound, ultrasound, infrasound, cavitation.</td>
</tr>
<tr>
<td>Thermal</td>
<td>Heating, cooling, insulation, thermal expansion, phase/state change, endo- exo-thermic reactions, fire, burning, heat radiation, convection.</td>
</tr>
<tr>
<td>Chemical</td>
<td>Reactions, reactants, elements, compounds, catalysts, inhibitors, indicators (pH), dissolving, crystallization, polymerisation, odour, taste, change in colour, pH.</td>
</tr>
<tr>
<td>Electric</td>
<td>Electrostatic charges, conductors, insulators, electric field, electric current, superconductivity, electrolysis, piezo-electrics, ionisation, electrical discharge, sparks.</td>
</tr>
<tr>
<td>Magnetic</td>
<td>Magnetic field, forces and particles, induction, electromagnetic waves (X-ray, Microwaves, etc.), optics, vision, colour/translucence change, image.</td>
</tr>
<tr>
<td>Intermolecular</td>
<td>Subatomic (nano) particles, capillary, pores, nuclear reactions, radiation, fusion, emission, laser, intermolecular interaction, surface effects, evaporation.</td>
</tr>
<tr>
<td>Biological</td>
<td>Microbes, bacteria, living organisms, plants, fungi, cells, enzymes.</td>
</tr>
</tbody>
</table>
Please write down your ideas here:
G.4 Computer-based Short Template

Some Questions First

1. I am a student from:
   - International
   - Australia
   - ATAR: [Space for input]

2. I am attending this tutorial.
   - Monday 08:30-09:30

3. I am using this type of device to access this web tool.
   - Desktop Computer
   - Laptop
   - Tablet With Keyboard
   - Handheld Tablet
   - Other

4. I always study using paper/printed materials (textbooks, printed lecture notes etc.).
   - Strongly Disagree
   - Disagree
   - Slightly Disagree
   - Not Sure
   - Slightly Agree
   - Agree
   - Strongly Agree
   - Add Comment

5. I always study using electronic materials (computer, e-books etc.).
   - Strongly Disagree
   - Disagree
   - Slightly Disagree
   - Not Sure
   - Slightly Agree
   - Agree
   - Strongly Agree
   - Add Comment

[Begin Using the Tool]

Setup the Problem

Step 1: What is name of the object you are trying to affect? [Barnacles]

What is the required outcome? [Remove barnacles from the ship]

Step 2: The graphical model solution proposed by Rule 1 is sketched below (updates automatically):

![Graphical model solution](image)

Written Model Solution (updates automatically):
I am looking for some new Field, which influences the Barnacles in such a way that remove barnacles from the ship is achieved.

[Restore]

[Back to Questions] [Next to Generate Ideas]
Generate Ideas

**Step 2:** Write down your ideas to solve the problem using fields of MATCEMIB:

*I am looking for some new Field, which influences the Barnacles in such a way that remove barnacles from the ship is achieved.*

<table>
<thead>
<tr>
<th>Fields</th>
<th>Some Interactions and Substances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical</td>
<td>Gravitation, collisions, friction, direct contact, vibration, resonance, shocks, waves, gas/fluid dynamics, wind, compression, vacuum, mechanical treatment and processing, deformation, mixing, additives, explosion.</td>
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<td>Acoustic</td>
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<td>Heating, cooling, insulation, thermal expansion, phase/state change, endo-exo-thermic reactions, fire, burning, heat radiation, convection.</td>
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<tr>
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<td>Reactions, reactants, elements, compounds, catalysts, inhibitors, indicators (pH), dissolving, crystallisation, polymerisation, odour, taste, change in colour, pH.</td>
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<td>Electric</td>
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<td>Intermolecular</td>
<td>Subatomic (nano) particles, capillary, pores, nuclear reactions, radiation, fusion, emission, laser, intermolecular interaction, surface effects, evaporation.</td>
</tr>
<tr>
<td>Biological</td>
<td>Microbes, bacteria, living organisms, plants, fungi, cells, enzymes.</td>
</tr>
</tbody>
</table>

Hit the barnacles with a hammer so they fall off.
Pour acid on the barnacles so that they dissolve and detach from the ship.
Find a predator which will eat the barnacles, thus removing them from the ship.
I am looking for some new Field, which influences the Barnacles in such a way that remove barnacles from the ship is achieved.

Hit the barnacles with a hammer so they fall off.

Pour acid on the barnacles so that they dissolve and detach from the ship.

Find a predator which will eat the barnacles, thus removing them from the ship.
Appendix H:
Experiment 1 Questionnaires

H.1 First Year Student Pre-Experiment Questionnaire

I have completed High School study in (please circle):
Australia (ATAR: ) Overseas

I have used Substance-Field Analysis before (please circle):
Yes No

I always study using electronic materials (computer, e-books etc.):
Strongly Agree 7 6 5 4 3 2 1 Strongly Disagree

I always study using paper/printed materials (textbooks, printed lecture notes etc.):
Strongly Agree 7 6 5 4 3 2 1 Strongly Disagree
H.2 Third and Postgraduate Year Pre-Experiment Questionnaire

1. I always study using electronic materials (computer, e-books etc.):
   Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

2. I always study using paper/printing materials (textbooks, printed lecture notes etc.):
   Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

3. I am very good at problem solving:
   Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

4. I am certain that I am able to resolve any problem I will face:
   Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

5. I come up with novel ideas on quite a regular basis:
   Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

6. I usually have many concepts for how to solve a problem I am facing:
   Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

7. I am a student from (please circle):
   Australia          International

8. I am enrolled in this type of course (please circle):
   Undergraduate      Postgraduate

9. I have seen or used Substance-Field Analysis before (please circle):
   Yes        No
Appendix H: Experiment 1 Questionnaires

H.3 Third and Postgraduate Year Student Post-Experiment Questionnaire

1. **This tool helped me to produce more solution ideas than I initially thought I may come up with.**
   
<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

2. **This tool helped me to consider a wider range of knowledge areas than I initially thought I may have used.**
   
<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

3. **This tool has increased my confidence in my ability to problem solve, even if only a little.**
   
<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

4. **This tool has helped me to reflect on my problem solving abilities and how I may be able to further improve them.**
   
<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Strongly Agree</th>
</tr>
</thead>
</table>

5. Any other comments?
H.4 Responses to Questionnaires

**Table 44: Questionnaire Metrics and Associated Questions**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Question</th>
<th>Measured Using</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use of Digital Materials</td>
<td>I always study using electronic materials (computer, e-books etc.).</td>
<td></td>
</tr>
<tr>
<td>Use of Print Materials</td>
<td>I always study using paper/printed materials (textbooks, printed lecture notes etc.).</td>
<td></td>
</tr>
<tr>
<td>Problem-solving Abilities</td>
<td>I am very good at problem solving.</td>
<td></td>
</tr>
<tr>
<td>Problem-solving Self-efficacy</td>
<td>I am certain that I am able to resolve any problem I will face.</td>
<td></td>
</tr>
<tr>
<td>Creative Tendency</td>
<td>I come up with novel ideas on quite a regular basis.</td>
<td></td>
</tr>
<tr>
<td>Creative Fluency</td>
<td>I usually have many concepts for how to solve a problem I am facing.</td>
<td></td>
</tr>
</tbody>
</table>

**Table 45: Responses to Questions. All except ATAR used Likert Scale 1-Strongly Disagree to 7-Strongly Agree.**

<table>
<thead>
<tr>
<th>Year Level</th>
<th>Template</th>
<th>Mode</th>
<th>N</th>
<th>Metric Mean (SD)</th>
<th>ATAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Use of Digital Materials</td>
<td>Use of Print Materials</td>
</tr>
<tr>
<td>1st Year</td>
<td>Extended</td>
<td>PPG</td>
<td>26</td>
<td>4.65 (1.50)</td>
<td>4.42 (1.53)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>44</td>
<td>5.30 (1.52)</td>
<td>4.51 (1.67)</td>
</tr>
<tr>
<td>3rd Year</td>
<td>Extended</td>
<td>PPG</td>
<td>34</td>
<td>5.24 (1.16)</td>
<td>4.21 (1.34)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>45</td>
<td>5.03 (1.43)</td>
<td>4.16 (1.85)</td>
</tr>
<tr>
<td>Postgraduate</td>
<td>Extended</td>
<td>PPG</td>
<td>27</td>
<td>5.44 (1.19)</td>
<td>4.48 (1.70)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>10</td>
<td>5.56 (1.60)</td>
<td>5.00 (2.06)</td>
</tr>
<tr>
<td>3rd Year</td>
<td>Short</td>
<td>PPG</td>
<td>42</td>
<td>4.90 (1.45)</td>
<td>4.83 (1.64)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>30</td>
<td>4.93 (1.70)</td>
<td>4.83 (1.77)</td>
</tr>
</tbody>
</table>
### Table 46: Statistical Significance between groups

<table>
<thead>
<tr>
<th>Year Level</th>
<th>Template</th>
<th>Mode</th>
<th>N</th>
<th>Metric Mean (SD)</th>
<th>Use of Digital Materials</th>
<th>Use of Print Materials</th>
<th>Problem-solving Abilities</th>
<th>Problem-solving Self-efficacy</th>
<th>Creative Tendency</th>
<th>Creative Fluency</th>
<th>ATAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Year</td>
<td>Extended</td>
<td>PPG</td>
<td>26</td>
<td></td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>n.s.s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>44</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Year</td>
<td>Extended</td>
<td>PPG</td>
<td>34</td>
<td></td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postgraduate</td>
<td>Extended</td>
<td>PPG</td>
<td>27</td>
<td></td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3rd Year</td>
<td>Short</td>
<td>PPG</td>
<td>42</td>
<td></td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>n.s.s</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CBG</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

n.s.s – not statistically significant, s.s – statistically significant, N/A – not applicable
Appendix I: Example Returned Templates

I.1 Returned Pen-and-paper Template (one page only)

Step 1) State the required outcome (what would you like to happen with the Barnacles. Please write over the grey letters “Required outcome” below):

Step 2) Complete the written form of model solution proposed by the following triad:

Step 3) Transform the model solution into ideas using fields of MATCEMIB. Write down your ideas:

**Mechanical field**

- Gravitational or gravity force.
- Interactions and phenomena associated with direct contact e.g. collisions.
  
  "Pour chemical liquid remover onto barnacles."

- Vibration, resonance, shocks, waves (excluding acoustic waves).

- Phenomena related to gas and fluid dynamics, wind, pressure, compression, vacuum.
  
  "High pressure water."

- Acts and events of mechanical treatment and processing: machining, drilling, land cultivation, etc.
  
  "Hill the barnacles away (removal)."

- Interactions linked to deformation, mixing, additives (without chemical reactions), insertion, extraction, removal, attachment, etc.

- Explosion (considered not as a process per se, but rather as a way to change/alter substances by means of explosion).
I.2 Submitted Ideas from Computer-Based Template (extracted from database)

<table>
<thead>
<tr>
<th>Category</th>
<th>Ideas</th>
</tr>
</thead>
</table>
| Mechanical | 1. Shaken and thrown from height  
2. Scraping them  
3. Vibrate the Hull to a certain oscillating frequency  
4. Using a super strong vacuum cleaner  
5. use power tool-- saw  
6. Scrape the paint layer and filing them  
7. use micro explosion at some parts |
Appendix J:
Experiment 2 Template

Please complete these questions before starting the experiment: (please circle responses)

1. I am a student from:
   Australia International

2. I am enrolled in this type of course:
   Undergraduate Postgraduate

3. During the week 2 tutorial, I completed the idea generation task using:
   Pen and Paper Web-interface Was not present

4. Have you changed the tutorial you are attending since week 2?
   No Yes
Please write down your ideas here:
Appendix K: Experiment 3 Templates

K1 Pen-and-paper Template

1. I am comfortable using the internet to contribute towards learning activities.

Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

2. I am very good at problem solving:

Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

3. I am certain that I am able to resolve any problem I will face:

Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

4. I come up with novel ideas all the time:

Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

5. I always have many concepts for how to resolve a problem I am facing:

Strongly Disagree  1  2  3  4  5  6  7  Strongly Agree

6. I am a student from:

Australia  International

7. I studied the following subjects during my two last years of high school:

Physics  Chemistry  Biology

8. ATAR (optional):

9. Anonymous ID:

\[ s \overline{3} 1 \quad 2 \overline{3} 4 \overline{5} 6 \]
\[ \overline{4} \overline{5} 9 \]

In case of a follow up study, it is useful for us to be able to anonymously match participants from this study to the next.

Following these instructions will make an anonymous, non-identifiable way of matching participants from this study to any future study.

Please determine this value from your student number and write it below.
Appendix K: Experiment 3 Templates

Before you begin, please answer the following question:

I am confident that I will be able to effectively resolve the problem I have been presented with:

<table>
<thead>
<tr>
<th>Strongly Disagree</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fields</strong></td>
<td><strong>Some Interactions and Substances</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical</td>
<td>Gravitation, collisions, friction, direct contact, vibration, resonance, shocks, waves, gas/fluid dynamics, wind, compression, vacuum, mechanical treatment and processing, deformation, mixing, additives, explosion.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Acoustic</td>
<td>Sound, ultrasound, infrasound, cavitation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal</td>
<td>Heating, cooling, insulation, thermal expansion, phase/state change, endo-exo-thermic reactions, fire, burning, heat radiation, convection.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical</td>
<td>Reactions, reactants, elements, compounds, catalysts, inhibitors, indicators (pH), dissolving, crystallisation, polymerisation, odour, taste, change in colour, pH.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric</td>
<td>Electrostatic charges, conductors, insulators, electric field, electric current, superconductivity, electrolysis, piezo-electrics, ionisation, electrical discharge, sparks.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic</td>
<td>Magnetic field, forces and particles, induction, electromagnetic waves (X-ray, Microwaves, etc.), optics, vision, colour/translucence change, image.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intermolecular</td>
<td>Subatomic (nano) particles, capillary, pores, nuclear reactions, radiation, fusion, emission, laser, intermolecular interaction, surface effects, evaporation.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biological</td>
<td>Microbes, bacteria, living organisms, plants, fungi, cells, enzymes.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please write down your ideas here:
Appendix K: Experiment 3 Templates

1. I am confident that I have effectively resolved the problem I was presented with.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

2. I would prefer to complete this activity using a web template, rather than pen-and-paper.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

3. I would complete this activity more effectively using a web template, rather than pen-and-paper.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

4. I would like to have activities like this available to help develop my problem solving skills.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

5. I produced more solution ideas than I initially thought I would come up with.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

6. I considered a wider range of knowledge areas than I initially thought I would have used.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

7. This activity has helped me to reflect on how I may be able to improve my problem solving skills.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

8. The presented table of hints was very useful for generating ideas.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

9. If the presented table of hints was very helpful, how did it help you?

10. This template was easy to use and understand.
    Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

11. What can be done to improve this template?
## K.2 Computerised Template

1. I am very comfortable using computers for university related learning activities.
   - Strongly Disagree 1 ≤ 2 ≤ 3 ≤ 4 ≤ 5 ≤ 6 ≤ 7 Strongly Agree

2. I am very good at problem solving.
   - Strongly Disagree 1 ≤ 2 ≤ 3 ≤ 4 ≤ 5 ≤ 6 ≤ 7 Strongly Agree

3. I am certain that I am able to resolve any problem I will face.
   - Strongly Disagree 1 ≤ 2 ≤ 3 ≤ 4 ≤ 5 ≤ 6 ≤ 7 Strongly Agree

4. I come up with novel ideas all the time.
   - Strongly Disagree 1 ≤ 2 ≤ 3 ≤ 4 ≤ 5 ≤ 6 ≤ 7 Strongly Agree

5. I always have many concepts for how to solve a problem I am facing.
   - Strongly Disagree 1 ≤ 2 ≤ 3 ≤ 4 ≤ 5 ≤ 6 ≤ 7 Strongly Agree

6. I am a:
   - ○ Local Student  ○ International Student

7. I studied the following subjects (or equivalent) during my two last years of high school (select all that apply):
   - ☐ Physics  ☐ Chemistry  ☐ Biology  ☐ Further  ☐ Mathematical  ☐ Specialist
   - ☐ Mathematics  ☐ Methods

8. ATAR (optional):
   - [ ]

9. Anonymous ID: [ ]

Using your student number, please follow the instructions below to write down an anonymous, non-identifiable id for matching participants from this study to any future study.

E.g. If your number is s3123456, please write 459:

```
\ + /  \ + /  \ + /
4  5  9
```

After being shown the presented problem, please answer the following question:

10. I am confident that I will be able to effectively resolve the problem I have been presented with.
   - Strongly Disagree 1 ≤ 2 ≤ 3 ≤ 4 ≤ 5 ≤ 6 ≤ 7 Strongly Agree
### Appendix K: Experiment 3 Templates

<table>
<thead>
<tr>
<th>Fields</th>
<th>Some Interactions and Substances</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mechanical</strong></td>
<td>Gravitation, collisions, friction, direct contact, vibration, resonance, shocks, waves, gas/fluid dynamics, wind, compression, vacuum, mechanical treatment and processing, deformation, mixing, additives, explosion.</td>
</tr>
<tr>
<td><strong>Acoustic</strong></td>
<td>Sound, ultrasound, infrasound, cavitation.</td>
</tr>
<tr>
<td><strong>Thermal</strong></td>
<td>Heating, cooling, insulation, thermal expansion, phase/state change, endo- exo-thermic reactions, fire, burning, heat radiation, convection.</td>
</tr>
<tr>
<td><strong>Chemical</strong></td>
<td>Reactions, reactants, elements, compounds, catalysts, inhibitors, indicators (pH), dissolving, crystallisation, polymerisation, odour, taste, change in colour, pH.</td>
</tr>
<tr>
<td><strong>Electric</strong></td>
<td>Electrostatic charges, conductors, insulators, electric field, electric current, superconductivity, electrolysis, piezo-electrics, ionisation, electrical discharge, sparks.</td>
</tr>
<tr>
<td><strong>Magnetic</strong></td>
<td>Magnetic field, forces and particles, induction, electromagnetic waves (X-ray, Microwaves, etc.), optics, vision, colour/translucence change, image.</td>
</tr>
<tr>
<td><strong>Intermolecular</strong></td>
<td>Subatomic (nano) particles, capillary, pores, nuclear reactions, radiation, fusion, emission, laser, intermolecular interaction, surface effects, evaporation.</td>
</tr>
<tr>
<td><strong>Biological</strong></td>
<td>Microbes, bacteria, living organisms, plants, fungi, cells, enzymes.</td>
</tr>
</tbody>
</table>

Please write down your ideas to solve the problem below (consider using the concepts listed above):
## Appendix K: Experiment 3 Templates

1. I am confident that I have effectively resolved the problem I was presented with.
   - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

2. I would prefer to complete this activity using a pen-and-paper template, rather than a web based one.
   - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

3. I am confident that I would complete this activity more effectively using a pen-and-paper template, rather than a web based one.
   - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

4. I would like to have activities like this one available in the future, to assist in developing my problem solving skills.
   - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

5. If activities like this one are made available in the future, I would prefer to use a web based interface to engage in the activity, rather than pen-and-paper.
   - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

6. What reason would you give for your response to question 5? (optional)
   - 

7. I was able to produce more solution ideas than I initially thought I may come up with.
   - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

8. I was able to consider a wider range of knowledge areas than I initially thought I may have used.
   - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

9. This activity has helped me to reflect on how I may be able to improve my problem solving skills.
   - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

10. The presented table was very useful for generating ideas.
    - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

11. If the presented table was very helpful, how did it help you? (optional)
    - 

12. This template was easy to use and understand.
    - Strongly Disagree [ ] [ ] [ ] [ ] [ ] [ ] Strongly Agree

13. What can be done to improve this template? (optional)
    - 

< Back  > SUBMIT
Appendix L: 
Contributions to Research Publications During Candidature

Table 1 details the research publications which were published during the candidature, and in-progress manuscripts.

Detailed below is a break-down of the main contributions I made to each research publication and in-progress manuscript, so that this is clear to the reader.


   - Contribution to paper: 70%.
   - Conducted literature review.
   - Responsible for overall design of the study, and management of the study. Arranged consultation and collaboration with academics from other universities who had experience in this type of study design.
   - Compiled list of all electrical engineering programs in Australia and New Zealand. Compiled lists of all the courses in those programs, and the associated publicly accessible course outlines. Created metrics and evaluation instructions.
   - Conducted first stage analysis of course outlines. This included analysis of over 1100 course outlines.
   - Distributed list of 50 course outlines to co-authors, along with evaluation instructions. Received evaluations back from co-authors.
   - Collaborated all data sets. Analysed data sets, carried out evaluation, and interpreted results.
   - Wrote structured abstract. Amended structured abstract according to co-authors’ suggestions. Submitted structured abstract for inclusion at conference.
   - Wrote draft paper. Amended paper according to co-authors’ suggestions. Submitted paper for inclusion at conference. Amended paper according to suggestions provided by reviewers. Submitted final version for inclusion at conference.
   - Presented research findings and paper at conference.


   - Contribution to paper: 70%.
   - Conducted literature review.
Appendix L: Contribution to Research Publications During Candidature

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- Distributed list of 50 course outlines to co-authors, along with evaluation instructions. Received evaluations back from co-authors.

- Collaborated all data sets. Analysed data sets, carried out evaluation, and interpreted results.

- Wrote draft manuscript. Amended manuscript according to co-authors’ suggestions. Submitted manuscript to journal. Amended manuscript according to suggestions provided by reviewers. Submitted manuscript revision to journal.


- Contribution to paper: 70%.

- Conducted literature review.

- Developed and finalised the overall design of the study.

- Created resources required to conduct the experiment. This included designing and implementing pen-the-paper templates, computer-based software applications, and powerpoint slides.

- Facilitated and ran experiments during class sessions to gather data.

- Digitised pen-and-paper templates, extracted data recorded from software applications and organised it into easy-to-read format, and created data evaluation templates. Sent all to co-authors for evaluation. Received evaluations back from co-authors.

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Appendix L: Contribution to Research Publications During Candidature

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