AN EXPLORATION OF STUDENTS’ PERCEPTIONS AND ATTITUDES TOWARDS CREATIVITY IN ENGINEERING EDUCATION

by

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Abstract

This study used a mixed methods approach to develop a broad and deep understanding of students’ perceptions towards creativity in engineering education. Studies have shown that students’ attitudes can have an impact on their motivation to engage in creative behavior. Using an ex-post facto independent factorial design, attitudes of value towards creativity, time for creativity, and creativity stereotypes were measured and compared across gender, year of study, engineering discipline, preference for open-ended problem solving, and confidence in creative abilities. Participants were undergraduate engineering students at Queen’s University from all years of study. A qualitative phenomenological methodology was adopted to study students’ understandings and experiences with engineering creativity. Eleven students participated in one-on-one interviews that provided depth and insight into how students experience and define engineering creativity, and the survey included open-ended items developed using the 10 Maxims of Creativity in Education as a guiding framework.

The findings from the survey suggested that students had high value for creativity, however students in fourth year or higher had less value than those in other years. Those with preference for open-ended problem solving and high confidence valued creative more than their counterparts. Students who preferred open-ended problem solving and students with high confidence reported that time was less of a hindrance to their creativity. Males identified more with creativity stereotypes than females, however overall they were both low. Open-ended survey and interview results indicated that students felt they experienced creativity in engineering design activities. Engineering creativity definitions had two elements: creative action and creative characteristic. Creative actions were associated with designing, and creative characteristics were
predominantly associated with novelty. Other barriers that emerged from the qualitative analysis were lack of opportunity, lack of assessment, and discomfort with creativity.

It was concluded that a universal definition is required to establish clear and aligned understandings of engineering creativity. Instructors may want to consider demonstrating value by assessing creativity and establishing clear criteria in design projects. It is recommended that students be given more opportunities for practice through design activities and that they be introduced to design and creative thinking concepts early in their engineering education.
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Chapter 1

Introduction

Undergraduate engineering faculty and administrators in Canada need to constantly update their curriculums to abide by the accreditation criteria defined by Engineers Canada, the national organization that regulates the practice and education of engineering. Recently, accreditation criteria have had an increasing emphasis on developing design skills in engineering students. Engineers Canada states that engineering design is a creative and iterative approach to solving open-ended problems [1]. Because engineering programs must demonstrate that its graduates have an acceptable level of engineering design competency, it follows that creativity is an important skill that must be developed in engineering students, as creativity has been shown to be an essential tool for effective problem solving [2]. Not only do creative abilities compliment technical skills and sound problem solving approaches, employers now expect new engineering graduates to be creative thinkers [3].

To illustrate creativity’s role in engineering, Cropley distinguishes between two types of problem solving: (a) routine and (b) creative. This problem solving paradigm can be seen in Figure 1. According to this model, problems that are addressed by old solution are classified as “Routine”. Old solutions, that is solutions that have precedence and are well defined, that are used to address old problems results in “Replication”. While replication problem solving is important to engineering practice, it does not lead to new ideas and innovation. When old solutions are used to solve new problems, “Stagnation” results where no progress is made. On the other hand, if problems are approached using new solutions, creative problem solving can occur. Implementing new solutions to old problems results in “Forward Incrementation” where small improvements
are made on current solutions. When new solutions are used to address new problems, either “Redirection” or “Reinitiation” occurs. “Redirection” takes precedence when new technology opens up new possibilities to solving problems that were not considered before, and “Reinitiation” ensues when current problems can only be solved by using new technologies and approaches. In essence, creativity is a specialized form of problem solving which helps enable engineers to solve society’s most complex problems [2].

![Figure 1: Creative and routine problem solving paradigms](image)

Despite that research has shown how creativity is an essential skill that is necessary for solving new, complicated engineering problems and that it is a process that can be taught and nurtured, there appears to be a lack of opportunities to develop creative skills in engineering education [4]
Cropley identifies a disconnect between engineering education and creativity and argues that engineering education programs are not adequately cultivating creative abilities in engineering students. He postulates that these disconnects are rooted in problems of institutional inertia and resistance to change, the trend toward offering unique and specialized engineering programs, a lack of knowledge of the nature of and attitudes towards engineering creativity, and a lack of methods for implementing creativity in engineering classrooms.

Research has shown that attitudes can have a large impact on student learning in engineering [6]. In the case of engineering creativity, negative attitudes can deter students from developing creativity skills in their undergraduate engineering education, which can have an overall impact on the open-ended problem solving abilities of new engineering graduates. Conversely, positive attitudes can increase engagement in learning. Understanding students’ attitudes towards creativity can contribute to well-informed development of engineering pedagogy, curriculum, and polices aimed at promoting creativity. Hence, the purpose of this study was to investigate undergraduate engineering students’ attitudes towards creativity and explore the context of these attitudes through their perceptions and experiences in engineering education.
Chapter 2

Literature Review

The goal of engineering education is to teach students the skills they need to be prepared for an engineering career. These skills involve using theory and knowledge from math and science to solve real-world problems. Some problems are closed-ended in nature, which usually require using well established methods and procedures to come to a final correct result. Other problem solving is open-ended where there are several different paths that can be followed with many potential successful solutions [2]. Engineers need to consider the functionality of their designs, as well as the economic, environmental, and social impacts. Considering all the elements of engineering design, students need to be good critical thinkers and creative problem solvers. Creativity allows engineers to solve new and challenging problems or approach old problems in different ways [2] [7] [8]. For this reason, many engineering practitioners and researcher agree that it is an importance skill to develop in engineering education [2] [9] [10].

Creativity has been shown to be a convoluted and multidimensional construct. The majority of the literature on creativity in engineering education focuses on: (a) definitions of creativity, (b) pedagogical practices to promote and enhance student creativity, (c) assessment of creative attributes, (d) attitudes and experiences of engineering creativity, (e) barriers to creativity, and (f) motivation for creativity. Overall, publications of research on engineering creativity is limited, making it necessary to review creativity literature in different, but closely related contexts. The rest of this chapter provides an overview of the relevant education and engineering education literature that informs the purpose of this study.
2.1 Definitions of Creativity

A perpetual debate amongst researchers in education and engineering education revolves around the definition of creativity. One of the central challenges to understanding creativity’s role in engineering education is understanding exactly what it means to be creative. Before instructors can be expected to teach and promote creativity and for students to learn and embrace creativity, it is important to have a common understanding [2] [11]. Latent constructs, such as creativity, are susceptible to an assortment of interpretations. The literature supports clearly defining creativity so expectations and learning objectives are clear to students and aligned with program requirements [11]. Education and engineering education researchers struggle with this conundrum which is clearly evident in the literature on definitions of creativity. It should not be surprising that definitions of creativity and even context-specific engineering creativity in the literature are vast and broad while encompassing some similar themes [12] [13].

Sternberg’s Handbook of Creativity identifies 61 different ways in which creativity can be defined [14]. One of these definitions is outlined by Taylor. He submits that creativity can fit into six domains that are summarized in Table 1 [15].

<table>
<thead>
<tr>
<th>Domain</th>
<th>Description</th>
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<tbody>
<tr>
<td>Gestalt or perception</td>
<td>Combining intersecting ideas</td>
</tr>
<tr>
<td>End product or innovation</td>
<td>Process of creating a new product or use of existing things</td>
</tr>
<tr>
<td>Aesthetic or expressive</td>
<td>Unique self-expression</td>
</tr>
<tr>
<td>Psychoanalytic or dynamic</td>
<td>Creativity is strictly dependent on personality</td>
</tr>
<tr>
<td>Solution thinking</td>
<td>Emphasis on process of divergent thinking</td>
</tr>
<tr>
<td>Varia</td>
<td>Other</td>
</tr>
</tbody>
</table>

From this classification system, engineering creativity encompasses four of the six domains. Combination of ideas is an important strategy for creativity and is employed during idea generation. Engineering is inherently connected with products, systems, and processes whether
they are completely new or feature incremental improvements to existing inventions. Similarly, Mumford defines creativity as the production of novel and useful products [18]. Through application of the design process, engineers consider stakeholder needs and application of scientific principle to generate solutions to problems. Solution thinking is directly related to engineering design and idea generation. As well, there are other aspects of engineering creativity that do not fit into the other domains.

Other interpretations of creativity are sometimes referred to as classical creativity because they embody typical stereotypes about creativity. This includes producing things that are novel, unique, and artistic [16] [17] [18]. Boden argues that creativity is the production of novelty. She distinguishes between p-creativity (psychological) and h-creativity (historical). P-creativity defines novelty with reference to things that are currently known, meaning things are classified as creative if they have never existed or been seen before. H-creativity uses previous ideas as a reference point for judging creativity [19]. This model used to define creativity can be adapted to creativity in different fields of study and in the context of the typical creative output such as visual art, literature, products, and processes.

Definitions of creative can describe either the creative product or the creative process. Taura and Nagai offer a unique definition of design creativity where they focus on three key elements: (a) “toward the future”, (b) “desirable figure”, and (c) “composing”. Their description is focused on design thinking aimed at promoting creativity. “Toward the future” is the beginning phase of the creative process where it must be understood that the future is uncertain but can be inductively estimated. The “desirable figure” refers to determining the objectives of the creative effort, and “composing” entails the construction or development of the design [20].
These are just a few definitions, illustrating the diversity of interpretations and explanations of creativity. As a result, definitions of creativity are often neglected when doing creativity research. Plucker, Beghetto, and Dow conducted a content analysis of creativity literature in the fields of psychology and education and found that 62% of papers had not explicitly defined creativity and the remaining 38% had considerably varied definitions [21]. Not only is the lack of a consistent definition of creativity a problem for educators, it is also a predicament for education researchers. Studies are difficult to compare when academics have varying positions on what creativity means.

Csikszentmihalyi proposes a systems view of creativity and maintains that the historical and social context of creativity cannot be ignored. Before designating something as creative, it is important to consider where creativity occurs. He explains that something creative cannot be attributed to the individual’s action, rather creativity encompasses three dynamisms: (a) field (the social context that identifies creative variations of ideas), domain (peers to select creative ideas and a platform to disseminate creative ideas), and individual (agent of creative change). Through the interaction of these three forces, creativity can occur [22]. Csikszentmihalyi’s emphasis on the interpretation of creativity through context supports a unique definition for engineering creativity.

Marquis and Henderson researched definitions of creativity from university instructors across Ontario. They found that most interpretations had common themes that aligned with classical definitions of creativity. Many responses discussed the mindset required for creativity in their particular field. In comparing definitions across different fields of study, Marquis and Henderson, in contrast to Csikszentmihalyi, concluded that definitions of creativity did not exemplify subject specific characteristics, however engineering and science instructors showed a larger agreement with the actuality of context specific definitions [12].
Even with domain-specific engineering, there are a multitude of definitions. An issue from the European Journal of Engineering Education featuring articles on engineering creativity had 13 unique definitions for 13 different articles [23]. Other studies corroborate the variety of existing definitions of engineering creativity. Zappe, Mena, and Litzinger’s paper investigating the conceptualization of creativity in engineering education research found no consistent definition of the construct across 16 different articles. However, they did note that there were common themes of problem solving, originality, and usefulness [13].

Research has shown that engineering students can interpret creativity in several different ways. Some define creativity as generating a novel solution [9] [24] [25] [26]. Others focus on approaching existing problems in different ways [9]. Bjorner and Bruun-Pedersen argue that these views of creativity imply that the product being designed has a large implication on how students view creativity. Their focus groups led them to the conclusion that students have many different perceptions of engineering creativity [9].

In their engineering creativity research, Bjorner and Kofoed emphasized that engineering creativity cannot be simplified to strictly a cognitive approach or description of a result. This mindset led to the conclusion that creativity has both macro-level definitions, that being the creativity environment, and micro-level definitions, focusing on products, processes, and individual characteristics. In their review of the literature, they found that most creativity research was focused more on micro-level creativity, and less on macro-level. They concluded by clarifying their definition of creativity; the production of something novel and appropriate in a given social context [27].
Mishra identified the benefits of having a clear definition of creativity. She explained that a coherent definition aligns the understandings of engineering creativity across individuals and institutions, which plants the roots necessary to develop high quality evaluation tools. Through development of her own definition of creativity, she explained that creativity comprises three primary components: (a) novelty, (b) effectiveness, and (c) wholeness. In her explanation of novelty, terms are used such as unique, surprising, unusual, and revolutionary. However, creativity is not merely something novel, it must also serve a functional purpose. This functional purpose needs to be interpreted in the context for which it was developed, as creativity in one field may not be creative in another. Effectiveness is described using vocabulary that includes value, relevance, logical, functionality, and usefulness. Wholeness is related to terminology including organized, complex, attractive, and meticulous. [11].

Badran distinguished between definitions of creativity and innovation in the field of engineering. By referring to the roots of each of these terms, he associated these two definitions to the essence of the meaning of each word. “Most established dictionaries indicate that the root of innovation is innovâre, which means to renew or make changes. Consequently, innovation is adding something new to an existing product or process. ‘Create’, on the other hand, is defined, as to bring something to being, i.e. produce something novel, unique, original or something which has no equal in existence before” [p. 574, 228]. Badran makes an argument that is similar to Cooperrider’s definition of creativity; it is an ability to generate solutions that are novel and solve a known problem or challenge [16].

The purpose of this study was an exploration of the creativity environment which meant that conforming to a specific definition of engineering education was not necessary. Rather,
developing an understanding of students’ definitions of engineering creativity was a primary intention. Hence, the framework for a positive creativity environment was an important consideration, not the specific definitions of creativity.

2.2 Teaching Creativity

Much of the engineering education literature on creativity investigates teaching practices and resources to promote and encourage development of creativity skills. Scott, Leritz, and Mumford suggested, from their review of 70 prior studies on teaching creativity, that it is possible to enhance creative performance through well designed and executed training modules and workshops. They stated that creativity training that focuses on developing divergent thinking skills through the use of heuristics and realistic problems tended to be the most successful [29]. Several other studies support the notion that creativity is a skill that can be taught and enhanced, as opposed to being a skill that is entirely dependent on personality [10] [2]. Florida argues that every human has the capacity for creativity and implies creativity is a skill that can be taught and learned [30]. This notion is supported by research from De Bono who defines creativity as a skill involving patterning of systems, or the skill of lateral thinking by logical connections of self-organized information systems, all teachable skills [31].

To study barriers to creativity in engineering education, Kazerounian and Foley developed the 10 Maxims of Creativity in Education. These maxims outline an environment and approach to teaching creativity aimed at fostering engagement and development of creative abilities in engineering students. The 10 Maxims of Creativity in Education are described in Table 2 [32].
Table 2: The 10 Maxims of Creativity in Engineering

<table>
<thead>
<tr>
<th>Maxim</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Keep an Open Mind</td>
<td>Students should be taught to approach things from a different perspective. Students should recognize that the most obvious solution is not always the best.</td>
</tr>
<tr>
<td>Ambiguity is Good</td>
<td>Students should be taught to be comfortable when they do not have a clear idea what the final result will be.</td>
</tr>
<tr>
<td>Iterative Process that Includes Idea Incubation</td>
<td>Time must be given for students to go through iterations of their design and put the project in the back of their minds to encourage unconscious thought about the problem.</td>
</tr>
<tr>
<td>Reward Creativity</td>
<td>Creativity needs to be rewarded for it to be valued by students.</td>
</tr>
<tr>
<td>Lead by Example</td>
<td>Examples of innovators and research should be shared with students for encouragement.</td>
</tr>
<tr>
<td>Learning to Fail</td>
<td>Tolerance should be given for students who attempt creativity but are unsuccessful with their final designs.</td>
</tr>
<tr>
<td>Encouraging Risk</td>
<td>Recognition should be given to students who attempt more difficult endeavours.</td>
</tr>
<tr>
<td>Search for Multiple Answers</td>
<td>Ideation should be promoted so students do not immediately choose their first idea.</td>
</tr>
<tr>
<td>Internal Motivation</td>
<td>Topics should be relevant to students to promote intrinsic motivation.</td>
</tr>
<tr>
<td>Ownership of Learning</td>
<td>Students should have some choice and control over what they are learning.</td>
</tr>
</tbody>
</table>

The researchers explained that their intentions were to propose an educational paradigm that cultivates creativity in engineering students. This model was adopted for the framework of this study and guided the development of the open-ended survey questions and interview questions. It was selected because the nature of this study called for a framework specific to engineering creativity, rather than general creativity. As well, Cropley’s article and many other papers used to inform this study refer to Kazerounian and Foley when discussing barriers to creativity in engineering education.
Education literature suggests that creativity is best facilitated through open-ended problem solving and project based learning [33] [34] [35]. It is easy to see natural fit of engineering design with project based learning, and several studies have recognized the importance of open-ended design problems for promoting skills such as creativity [7] [8]. Robertson, Walther, and Radcliffe recommended starting students with problem based learning through engineering design early in their engineering education. They observed that courses such as drafting and CAD modelling constrained students’ perceptions of design and creativity because they were required to learn how to use visual representations of designs without a practical context for applying these skills [38].

In addition to open-ended project work, Cooperrider claims that project based learning encourages group idea generation. Correspondingly, he notes that creativity is better taught by mentoring groups of students rather than lecturing individuals [34]. The relationship between group work and creativity has been well established in the literature. Group collaboration has been shown to enhance creativity by giving students multiple perspectives to a problem and increases the quantity of ideas [33] [34].

It has been recognized that idea generation requires divergent thinking as opposed to convergent thinking [16]. Divergent thinking operates in the concept domain where there are multiple correct ideas. Convergent thinking dwells in the in the knowledge domain where the focus is finding the single correct solution [36]. Cropley and Cropley identify important characteristics that engineers need to succeed in divergent thinking. They include: (a) openness, (b) flexibility, (c) nonconformity, (d) willingness to take risks, (e) tolerance of ambiguity, and (f) self-efficacy [37]. The successful characteristics for divergent thinking are very similar to the 10 Maxims of
Creativity in Education. Though convergent thinking is not commonly associated to the creative process, Nygaard, Courtney, and Holtham explain that engineering creativity is unique. Both divergent and convergent thinking are required to generate multiple possible solutions while using the appropriate information and strategies to come to a final design from the various design ideas [39].

To help promote divergent thinking, studies in the literature advocate teaching industry used design tools. Pitso found that the TRIZ-based creativity model was able to positively impact students’ creative abilities [40]. Similarly, Daly et al. found that the Design Heuristics tool was able to increase the creativity of first year engineering students [41]. Other creativity strategies noted in the literature include analogical thinking (deliberately asking questions to promote further idea generation), brainstorming (submitting ideas without criticism), idea checklists (focusing idea generation on a checklist of areas of concentration for a problem), mind mapping (visual representation and structuring of ideas), and morphological analysis (generating ideas for sub-functions) [42].

2.3 Assessment of Creativity

Assessment of students’ skills and knowledge is an important aspect of engineering education. Some skills, such as knowledge of concepts in physics and mathematics, are relatively straightforward to assess and generally involves solving problems using standard procedures and equations. Other skills, such as creativity, are much more difficult to evaluate [43] [44]. Assessment methods have long been known to influence student attitudes towards their education [45]. Traditional testing methods aimed at replication of knowledge and emphasize training in technical skills do not promote creativity [2].
Berglund et al. argue that as creativity skills grow in importance for new engineering graduates, pedagogies must adapt by implementing less traditional assessment methods. They conducted a study at a university in Sweden where they introduced a new assessment approach and course module to promote creativity in engineering students. In addition to a conventional final examination with individual problem solving questions, students were required to work in groups and present projects in the style of thesis defences. The course structure was altered by having fewer lectures, increasing the time available for individual support on assignments, and shifting the focus to active learning techniques. Through their collection of qualitative data in this pilot study, Berglund et al. found that instructors were overwhelmed with the individual support time required. Because of the difficulty of the problems and concepts and considering the heavy workload for engineering students, instructors were hesitant with continuing with this teaching strategy. On the positive end, they found that students were more engaged with their learning and willing to accept alternative solutions. It was also found that there were significantly more students who passed the course compared to the class from the year before who did not receive the new assessment approach and creativity modules. Overall, students’ attitudes and grasping of course concepts improved from this change, contributing to the knowledge of assessment based practice to promote creativity skills in students [46].

Though there are studies on instrument development for measuring creativity, students usually feel that assessment of creativity in their engineering work is either non-existent or vague [4] [47]. Daly, Mosyjowski, and Seifert used a mixed methods study to explore engineering pedagogies that promote creativity. When focusing on assessment, they highlighted that students were not usually graded on the ideas that were generated in the first steps of the design process, even though instructors expressed the desire for students to ideate. There were instances when
evaluation was measured by quantity of ideas, however no consideration was given for fluency of those ideas [4].

Another creativity assessment aspect that was investigated by Daly, Mosyjowski, and Seifert was the development and iteration of proposed ideas. They resolved that the creative action of developing multiple concepts was assessed based on proper feasibility analysis, idea evaluation, and justification of design decisions. Design iteration was noted as being the most clearly assessed creativity criterion, where students were expected to present updated version of their designs periodically throughout the semester and rubrics reflected different project milestones. However, most assessment criteria were not explicit and had unclear descriptions that could be interpreted in many ways [4].

Instructors often express that creativity is not graded because there are no tools available to quickly and accurately assess this criterion [12]. Cropley’s review of creativity measurement tools revealed that there are instruments to measure cognitive processes including divergent thinking, as well as non-cognitive facets of creativity such as motivation and attitudes. He found that creativity tests were quite varied and categorized them by their focus on different elements of creativity which were: (a) product, (b) process, (c) motivation, (d) personal/ability. These tests had varying lengths and reliability results, with the more reliable tests usually having more items and taking up more time [43].

Cropley classified the Torrance Test of Creative Thinking (TCCT) as the most well-known test of divergent thinking capability [43]. Several studies in the engineering education literature have used this test to measure the creative abilities of students, and has shown to be particularly useful
when determining if a teaching method or tool has had an impact on the creativity of students [40] [48]. The TCCT measures six mental capacities through a verbal and nonverbal test section. Verbal items measure fluency, flexibility, and originality. Nonverbal questions measure fluency, originality, elaboration, abstractness of titles, and resistance to premature closure. Using these results, the TCCT can predict strengths in 13 different areas of creativity including abstract application and technical application [49].

Tests that focus on the product aspect of creativity generally measure originality, usefulness, complexity, and aesthetics of ideas [43]. The most recently developed test was the revised Creative Engineering Design Assessment (CEDA). The CEDA was developed in response to a lack of instruments that measure engineering creativity. Charyton et al. found that there were only two published instruments with reasonably reliability and validity. The Owens Creativity was developed in 1960 and focused on assessing mechanical designs, however it is out of print and no longer used. The Purdue Creativity Test was another instrument developed in 1960 that focused on fluency (quantity of uses based on the combination of two objects) and flexibility (different categories of use) [250]. Charyton et al. claim that the revised CEDA is beneficial because, in addition to measuring fluency, flexibility, and originality, it also assesses usefulness which is an important consideration for engineering creativity [49].

For measuring attitudes towards creativity, Cropley explained that the “Basadur Preference Scale” attempts to determine the likelihood of engagement and motivation to be creative by measuring attitudes towards creativity [43]. Basadur and Hausdorf pose that attitudes towards creativity are important to measure because they are susceptible to influence through
interventions and an appropriate environment [45]. This tool was used to measure students’ attitudes towards creativity for this inquiry.

Overall, there are several assessment instruments available to measure different aspects of engineering creativity, however their focus, development, and size vary. Mishra implores that there will always be difficulty measuring creativity because of the subjective nature of the construct, however with proper structure and guidelines for assessment tools, the subjectivity can be mitigated [11].

2.4 Attitudes and Experiences

Research indicates that students’ attitudes towards creativity affect their motivation to engage in creative behaviour [45]. Motivation has also been shown to be influenced by the creativity environment [32]. Hence, understanding students’ perceptions towards creativity, how they experience creativity, and how they understand creativity is valuable knowledge to have when trying to foster this ability. However, research on engineering students’ attitudes towards creativity is quite limited.

Walker and Gleaves conducted a study on student perceptions of creativity as an assessment criterion. They found that, as a consequence of the assessment methods, students had a vague notion of what constituted creativity. This also resulted in confusion amongst students with being creative but at the same time adhering to academic expectations. These results were attributed to unclear assessment criteria with subsequent misinterpretation of expectations [47].

Marquis and Henderson’s study on teaching creativity across subjects in Ontario universities shows that engineering instructors have positive attitudes towards creativity, but it does not
translate to practice because they perceive creativity as a skill that is difficult to teach and assess [12]. On the other hand, students show value for creativity in engineering and think creative training is necessary in engineering education [35] [12]. While Burkett et al. assert that students have value for creativity regardless of their background or experience, Atman, Kilgore, and McKenna concluded that only 30% of upper year students in their study valued creativity in engineering design [51] [52]. When measuring creative ability of undergraduate engineering students, Genco, Holtta-Otto, and Seepersad found that students in their freshman year were significantly more creative than senior students while the technical feasibility of their designs had no difference [53].

Bjorner and Bruun-Pedersen conducted a study on how university students in technical and science programs perceive creativity. Their mixed methods approach revealed that students felt creativity was context specific. They perceived creativity as being the creation of new solutions using modern technology to improve everyday life. Students also felt that they were more creative in the early stages of their projects, meaning creativity was easier in the idea generation stage more than the evaluation and iteration stages. Overall, students felt it was difficult to apply creative throughout the whole project. The authors explained that students had this sense of difficulty because of the limitations from the guidelines of the project and poor performing group members. They also found that students assumed their professors did not expect creativity because they understood the limitations of time and what was achievable with the heavy workload in undergraduate engineering [8]. Similarly, Burkett et al. concluded that students found being creative was more difficult and time consuming [51].
In Fila and Chakroun’s investigation of how engineering disciplines influence perceptions of creativity and innovation, they found that definitions of creativity were not just specific at the field of study, rather they were discipline specific. Table 3 outlines how students in each discipline interpreted the concept of innovation [54]. It is important to note that these findings were from a small qualitative study and are not necessarily generalizable, but they do support how different disciplines have distinctive experiences with creativity and innovation.

Table 3: Perceptions of innovation concepts by engineering discipline

<table>
<thead>
<tr>
<th>Aspect of Innovation</th>
<th>Perspectives from Engineering Majors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chemical</td>
</tr>
<tr>
<td>Context of innovation</td>
<td>Processes or product design</td>
</tr>
<tr>
<td>Design process</td>
<td>Sequential and iterative</td>
</tr>
<tr>
<td>Key information or knowledge</td>
<td>Scientific knowledge</td>
</tr>
<tr>
<td>Challenges to success</td>
<td>Models lack functionality in real application</td>
</tr>
<tr>
<td>Personal motivation</td>
<td>Gain new knowledge</td>
</tr>
</tbody>
</table>

In the literature, engineering students have been noted to have attitudes representative of risk aversion and discomfort with ambiguity. Toh and Miller conducted an inquiry into how students choose creative concepts in engineering design and the role of individual risk and ambiguity aversion. They commented that even though creativity is usually valued in engineering, creative ideas rarely make it passed the idea selection phase of the design process. Their results indicated that preference for creative ideas during concept selection had no impact on their creative abilities, however risk and ambiguity aversion were significantly correlated with creative concept selection and idea generation. They suggest that creativity during idea generation does not usually carry through during idea evaluation and selection [55].
2.5 Barriers to Creativity

The difficulty of teaching a complex construct like creativity has prompted several studies on the barriers towards creativity in education. Kazerounian and Foley investigated barriers towards creativity using their 10 Maxims of Creativity in Education as framework for the study. They compared the perceptions of university students and professors in engineering, sciences, and humanities and found that there was largest number of disconnects between engineering students and their professors. Overall, students experienced only one of the ten maxims and felt a lack of creative opportunities in their studies [32].

Some of the barriers that were extracted from the 10 Maxims of Creativity in Education and the disconnects between instructors and students were grounded in difficulties with having an open minded approach and the available time for applying creativity. Kazerounian and Foley reported that students felt their educational experiences had encouraged them to find the one correct answer using standard methods and procedures taught in class, leaving them feeling uncomfortable with problems that had many potential successful solutions with no clear path to get there. They also found that students did not want to go through iteration cycles for their designs because they just wanted to get to the answer and not waste time, a symptom of their heavy workload and extrinsic motivation. Students seemed to emphasize efficiency with generating course deliverables by relying on old, well-established solutions and methods [32].

Similarly, a study conducted by Fatima et al. looked at higher education students’ perceptions to creativity at Portuguese public universities. Their analysis of the results established that students felt that lack of time and opportunities was the most significant barrier to being creative. Other barriers that students agreed with were having a lack of motivation, as well as feeling inhibition
or shyness to engage in creative group work. However, they found that students did not feel that social repression was a barrier to their creativity [56]. Abdekhodae and Steele also reported that students felt there were not enough opportunities for creativity in engineering education [57].

First year engineering students have been shown to be susceptible to misconceptions about engineering creativity. In Daly et al.’s study on student perceptions of their own creative ideas, they found that students suffer from preconceived understandings of creativity. They observed that engineering students sometimes thought that creative ideas were original and had never been seen before. Furthermore, students automatically felt that any idea that had been thought of before was not creative and, as a result, students tended to develop something completely different as opposed to identifying the opportunity to modify or adapt existing solutions. Another misconception was that creative ideas were thought of as impractical. This misrule was closely associated with the notion that creative designs are so advanced that the technology does not exist to bring the concept to fruition. In other words, because creative ideas require something that does not currently exist, they are assumed to be impractical. The final misrule identified in the study was the belief that a creative concept had to be completely new and creative, leaving out opportunity for improvement or enhancement of existing products through creative adaptations or improvements. They found that these presumptive creative misrules impacted students’ idea generation activities. By affecting the type of ideas being generated and the subjective evaluation of those ideas, many concepts risk going unexplored or undeveloped [41].

Orhun and Orhun take a different viewpoint when explaining barriers to creativity by focusing more on the challenges faced by engineering faculties and administration. They explain that most current engineering programs have an emphasis on deductive learning and typically neglect
experimentation and inductive learning. This barrier was associated with the lack of opportunity for creativity in engineering education. Lack of multidisciplinary courses and projects was another recognized barrier [58].

Likewise, Cropley identifies barriers to creativity that are rooted in problems of pseudo-expertise, overspecialization, and a lack of creativity knowledge and associated value. Pseudo-expertise is problematic because students develop a sense that their technical knowledge improves their problem solving skills, when in reality these skills are only applicable to problems with well-defined constraints, a rarity in real world engineering. Programs with overspecialized engineering disciplines suffer from curriculums that focus on developing complex technical expertise at the expense of broader skills such as creativity. Lack of knowledge stems from the multiple different definitions of creativity and a lack of understanding of methods for implementing creativity in engineering classrooms [2] [59]. Marquis and Henderson corroborate these submissions as their results indicated that amongst Ontario university instructors, professors and TAs in science, technology, engineering, and math (STEM) fields felt less trained and had lower self-efficacy for instruction and evaluation of creativity than instructors in the arts and humanities [12].

One of the primary barriers for students applying creativity in their work is fixation, a phenomenon where students have difficulty utilizing divergent thinking after being exposed to examples of a solution, or after developing a solution that they think is the best and will be successful. When students suffer from fixation, the divergent thinking necessary for creativity becomes cumbersome [60]. Douglas et al. observed different levels of fixation amongst engineering students. In some cases, students suffered from extreme fixation or fixation throughout the majority of the design process. Extreme fixation was associated with being
overwhelmed by the challenge of solving large, complex open-ended problems. Other students showed moderate to low fixation, where they became or were uncertain of the decision made or process used [61].

2.6 Motivation for Creativity

Scholars have recognized the importance of understanding the motivations of students to engage in learning in order to encourage them while considering their sensitivities and individual differences. Kreitler and Casakin noted that while motivation levels of students for creativity may be the same, the themes that drive motivations can be very different [62]. This has implications on pedagogy because students will respond differently to various motivating stimuli. It suggests that motivation needs to be encouraged in multiple ways in order to reach all students.

Different theories have been used to study motivations for being creative. One of these theories is Expectancy-Value Theory, which postulates that motivation comes from students’ expectancies about how well they can perform a task and how much they value that task. Expectancy and value are assumed to directly influence performance, effort, and persistence. Motivation is also impacted by an individual’s beliefs about their ability to perform the task, perceived difficulty of the task, and personal goals with respect to the task [63]. Expectancy-Value Theory was adopted for the interpretation of motivational attitudes of students in this study.

Casakin and Kreitler conducted a study comparing the motivation for creativity between groups of engineering students and architecture students. Their results indicated that motivation varied across the two fields of study. They found that creativity can be promoted in engineering students by focusing on the functionality of their ideas during design activities. Conversely, architecture students were motivated by a non-functional approach, where functionality was deferred as a
primary concern. Furthermore, engineering students’ motivation was shown to have come from both environmental and personal considerations. Architecture students were characterized as being more focused on personal expression of uniqueness [64].

Kazerounian and Foley focused on extrinsic and intrinsic motivating factors. In their 10 Maxims of Creativity in Education, “Reward for Creativity” and “Internal Motivation” encompassed the motivational requirements for a positive creativity environment. They posed that students need both extrinsic (reward) and intrinsic (internal) motivation in order to be engaged with developing their creativity skills [32]. Marquis and Henderson found that most instructors, when they wanted to, encouraged creativity by awarding marks. Intrinsic motivation was often neglected [12]. However, literature suggests that encouraging intrinsic motivation is a more effective strategy at promoting engagement in creative behaviour [65] [66]. Conversely, Waks and Merdler argued that negative influences from extrinsic motivation outweigh the positive influences from both intrinsic and extrinsic motivation [67]. Csikszentmihalyi recommended low extrinsic and high intrinsic motivation to maximize students’ motivation for creativity [22].
Chapter 3

Research Design

3.1 Objectives and Research Questions

The purpose of this study was to contribute to our understanding of creativity in engineering education by exploring the perceptions of students towards the creativity environment in undergraduate engineering. The research questions guiding this study were:

1. What are students’ attitudes towards engineering creativity?
2. How do engineering students understand and experience creativity in engineering education?

To clarify the objectives of this research, sub-questions were developed for each research question. For Question #1, the sub-questions were:

a) Are there differences between attitudes towards engineering creativity based on gender, year of study, and engineering discipline?

b) Does preference for open-ended or closed-ended problem solving and confidence in creative ability impact attitudes towards creativity for engineering students?

The associated sub-questions for Question #2 were:

c) How do engineering students define creativity in the context of engineering?

d) What are the barriers to creativity in engineering education as perceived by students?

To investigate these research questions, a mixed methods approach was implemented by collecting both quantitative and qualitative data. A survey with closed-ended and open-ended items was developed to capture attitudes and understandings of engineering creativity with the goal of generalizing the results to engineering programs with similar curriculum designs. Semi-
structured interviews were used to get a deep and rich description of students’ experiences of creativity in engineering education and to elaborate on students’ understandings of creativity in an engineering context. Queen’s University undergraduate engineering students were used as data sources. They were invited to participate in the survey and requested to volunteer for one-on-one semi-structured interviews upon completion of the survey. This study focused on the perceptions of students towards the creativity environment in undergraduate engineering while perceptions of engineering professors and instructors were not considered in the scope of the research.

3.2 Methodology

This study’s methodology utilized a mixed methods approach because the nature of the research questions called for both an explanation of students’ attitudes towards engineering creativity and an exploration of students’ perceptions on creativity in engineering education. By using mixed methods, I was able to maximize the strengths of both quantitative and qualitative inquiry, not sacrificing breadth for depth or vice-versa [68]. Plano Clark and Creswell explain that mixed methods “can develop a more complete picture of a social phenomena that includes both trends and individuals’ experiences” [pp. 386, 269], with engineering creativity being the phenomenon in question. Accordingly, this methodology allowed for consideration of both the general trend of students’ attitudes towards engineering creativity and an in-depth exploration of the views students have towards the creativity environment in engineering education.

Mixed methods research is appropriate when a study poses two related research questions that require different approaches to thoroughly answer [69]. Measuring the attitudes of students and comparing group levels of respondents was required to answer the first research question, necessitating the use of a quantitative method. The second research question called for a qualitative exploration of the experiences students have with creativity in engineering education,
which may be a contributing factor to the bedrock of those attitudes and beliefs, offering an opportunity to develop new insights that would not be possible by reserving to only one methodology. My intent for using this approach was foremost to provide rich description of student experiences that, in conjunction with the survey measuring attitudes towards creativity, provide a comprehensive description of the phenomenon.

Mixed methods studies are defined by three elements: (a) timing, (b) priority, and (c) mixing. Timing refers to the order of data collection, priority relates to the emphasis of quantitative or qualitative data collection and analysis, and mixing pertains to how quantitative and qualitative results are combined to strengthen the study and align with the purpose of the inquiry [69]. The approach used for this study was a convergent parallel design (QUAN + QUAL) where quantitative and qualitative data were gathered and analyzed concurrently while placing equal emphasis on both data types for answering the study’s research questions. This mixed method design is depicted in Figure 2 which was adapted from Plano Clark and Creswell [69]. This research design involved simultaneous collection of data with separate interpretation followed by comparison of the results to make interpretations and develop valid and complete conclusions.

This mixed methods approach enabled myself to develop a broad and in-depth understanding of students’ attitudes and experiences with engineering creativity through an analysis of a wide variety of data sources. It allowed the study to have an emergent design where quantitative and qualitative data guided me to a more complete understanding of the creativity environment in engineering education through the perceptions of undergraduate engineering students.
3.2.1 Quantitative Methodology

An ex-post facto and independent factorial design were used to investigate attitudes of undergraduate engineering students towards creative thinking. As the study’s participants were students that were in the process of completing their undergraduate engineering education, an ex-post facto design was appropriate because their engineering education experiences had already exerted its effect on their attitudes towards creativity [70]. In contrast to experimental or quasi-experimental approaches, this study was not designed to survey students prior to entering an engineering program and measuring how their attitudes change by considering their engineering education experience as an intervention.

Pre-existing groups of engineering students were surveyed once in this research study during the winter semester of 2016. Engineering students were not randomly assigned to an engineering
discipline or year of study because, prior to conducting this study, students have made a personal
decision to pursue their desired engineering discipline (except for first year students). Their year
of study depended on their progress in their engineering programs at the time the study was
conducted. Therefore, non-random assignment and predisposed attitudes towards engineering
creativity influenced by their engineering education experience aligned with an ex-post facto
design [70].

Many independent variables were measured and used to compare attitudes towards creative
thinking which is characteristic of an factorial design. In most cases educational research cannot
attribute differences to a single factor due to confounding variables. By comparing various group
levels (independent variables) on different attitudinal constructs (dependent variables), it was
possible to examine the main effects on attitudes towards creativity [71].

3.2.2 Qualitative Methodology
Creswell elucidates that qualitative research is conducted when there is a need to explore the
complexities of an issue that cannot be attained through quantitative measurement and analysis
[72]. These complexities include the natural and contextual setting of the research subjects, the
multiple nuanced perspectives of individuals, and the inductive-deductive logic process of the
researcher acting as both the data collection instrument and data analyzer. The scope of Question
#2 was both broad and general, necessitating a qualitative approach to explore the complex
phenomenon of creativity in engineering education. Additionally, Merriam explains that the when
a researcher wants to answer questions relating to the meaning of an event, activity, or
phenomenon, qualitative research must be conducted [73]. It was clear that qualitative research
aligned with the purpose of the second research question, however the type of qualitative
methodology needed to be clarified so the lens and framework from which the study was being approached is transparent.

For this segment of the research, a phenomenological methodology was deemed appropriate. Creswell explains phenomenology as an approach to qualitative research that aims to “describe the common meaning for several individuals of their lived experiences of a concept or phenomenon” [pp. 76, 274]. The purpose of this methodology is to epitomize individual experiences into a composite description of the meaning and nuances of the phenomenon under investigation. This methodology guided qualitative data gathering in the open-ended survey questions and interview protocol, as well as the data analysis and interpretation of qualitative data. Creswell states that by collecting interview data in phenomenological research, findings and themes can be corroborated and discrepancies can be highlighted [72].

Based on Hirtle’s explanation of a social constructivist philosophy, I approached this study with the framework that individuals develop subjective meanings of their personal experiences and that these views are influenced by several dynamic factors [75]. This philosophy embraces the richness and complexity of these contextually based subjective views and requires consideration of the research participants’ unique circumstances [76]. This aligns with the purpose of my study which is to explore the meanings that students associate with their experiences of creativity in undergraduate engineering education and how these idiosyncratic views have been constructed. I employed a interpretivist approach to portray students’ perceptions of engineering creativity. In qualitative research, the researcher acts as the data recording instrument, therefore acknowledgement of my background with engineering creativity is required to clarify any
inherent introspective interpretations of the data gathered from the qualitative phase of the study [77].

3.2.2.1 Autobiographical Statement

My formal engineering education began after transferring from a physiology program into engineering. As I began my physiology degree I realized that the path I was on did not align with my long term career goals and I felt I was focusing too much on theoretical science rather than developing useful skills that could be applied in the real world. I chose engineering because I had peers in engineering programs who seemed to be developing the ability to approach problem solving in a practical and versatile manner. Upon transferring, I decided to major in aerospace engineering because I had always been interested in aviation and space flight.

My initial experience in engineering was adequate as I found I was more interested in topics of physics and mathematics than biology, but I found my program was lacking the applied science that sets engineering apart from a degree in pure science. When I reached third and fourth year, I began taking courses that were more specific to the aerospace discipline, however I felt limited because there was little course selection options and the design projects were heavily constrained and narrow in scope. I was disappointed because I felt we were not given the open-ended projects that required thinking outside of the box and applying our knowledge in unique and creative ways. Instead, I joined the rocketry club which became my creative outlet with respect to aerospace engineering.

In hindsight, I would not have chosen the aerospace discipline because I felt the program was too specialized for an undergraduate degree. Though I developed a solid background in fundamental
physics and fluid dynamics, I sensed that I was missing skills that I had anticipated developing by pursuing an engineering degree. I felt that I could only solve the problems that had been directly taught to me and that my design skills were lacking. This became especially evident when I had a summer internship at an aerospace manufacturing company where my lack of manufacturing knowledge made me feel like I was not contributing like a well-trained engineering intern should be contributing. This led to me to the realization that I wanted to help improve the way engineers are taught problem solving and design skills. After investigating educational opportunities including teacher’s college and a Master’s of Education, I decided to undertake the unique opportunity at Queen’s University to focus on researching engineering education.

During the first year of my Master’s degree, my experience as a teaching assistant (TA) for second and third year design courses gave me valuable insight into how students approach and learn engineering design. These courses were created, coordinated, and developed by my research supervisor, and may have influenced the design of this study and my interpretation of the results. I found that students tended to struggle with applying the design process and being creative with their open-ended design projects. I felt that students were too focused on the marks they were receiving for their design courses instead of embracing the opportunity to try something new and creative. When I attempted to encourage creativity through the feedback I gave them on their design reports, I found that not all students were responding positively. Consequently, I chose to study the topic of engineering creativity. After review of the engineering education literature and based on my experiences interacting with students, I was particularly interested in exploring the student perspective on the subject. I chose to design a study that would provide insight into how creativity is perceived by students with the hopes of informing engineering educators on how students experience engineering creativity. My completion of a narrow and specialized
engineering degree, in conjunction with my experience working as a TA for my supervisor’s engineering design courses that promote creative thinking, may have influenced my perceptions and understanding on engineering creativity.

3.3 Methods

3.3.1 Sampling

3.3.1.1 Population

The population of interest is undergraduate engineering students at Canadian universities. This includes students who are currently pursuing a Bachelor of Engineering (or equivalent) degree in any engineering discipline at a university that is accredited by Engineers Canada. Engineering students of all ages, years of study, and gender are considered part of this population. This is the population of interest because the objective of this study is to formulate recommendations that may have implications on accreditation criteria which is relevant to all engineering programs in Canada. All engineering programs in Canada are developed based on the same principles and accreditation requirements outlined by Engineers Canada [90]. Though these engineering programs will have different engineering disciplines, sizes, and student backgrounds [78], there are many commonalities such as the need to emphasize engineering design in their curriculums and the level of expertise of the faculty.

3.3.1.2 Sampling Design

Convenience sampling was used to gather survey data. As a graduate student in the Faculty of Engineering and Applied Science at Queen’s University, the undergraduate student body was accessible and contained 2,946 undergraduate engineering students as of the beginning of the 2015-16 academic year [79]. Queen’s University is representative of typical Canadian universities because students have the option to choose their engineering disciplines including chemical, civil,
electrical, and mechanical. There are also engineering disciplines that are more specialized including applied mathematics engineering, computer engineering, engineering chemistry, engineering physics, geological engineering, and mining engineering. First year engineering students do not declare their engineering discipline until the end of their first year of study meaning all engineering students take the same core engineering courses in their first year [80]. Most engineering programs at Canadian universities offer degrees in the core engineering disciplines and number of more specialized engineering disciplines, as well as having a common curriculum in their first year of study [78]. The Faculty of Engineering and Applied Science at Queen’s University have mandatory faculty-wide engineering design and professional practice course in the first two years of the engineering program, followed by subsequent multidisciplinary or discipline specific design courses in both third and fourth year. In many of these design courses, particularly in the mandatory courses in first and second year, students are taught the engineering design process and creative thinking tools, and are encouraged to generate creative solutions to open-ended design problems. The unique demographic of Queen’s University (student population and engineering curriculum) where the sample was collected may have implications on the generalizability of the results.

As engineering disciplines that are more specialized tend to have fewer enrolled students, non-proportional stratified sampling was employed to ensure that these sub-groups were large enough for statistical analysis and comparison to other engineering disciplines. Proportional stratified sampling was used for year of study and gender. For year of study, groups are approximately equal in size based on similar sizes cohorts. For gender, the Faculty of Applied of Science at Queen’s University has approximately 73% males and 27% females [80]. Differences in attitudes by gender was important to investigate because of the rising female population in engineering
programs. Engineering has traditionally been a male dominated field of study, however increasing female enrolment calls for understanding if there are any differences in attitudes between males and females. This knowledge will have implications on teaching strategies, educational policies, and recruitment practices, and will help instructors adapt to a changing student demographic. After the survey was made available for three weeks, the remainder of the semester was dedicated to stratifying the sample by contacting classes of the appropriate engineering year and discipline.

3.3.1.3 Interview Participant Selection

At the end of the survey, students were directed to a second survey asking for volunteers to participate in the interview phase of the study. Students were asked to provide their gender, year of study, engineering discipline, name, email address, and phone number (optional) if they were interested in participating. Interviewees were selected by a third party from the list of students who volunteered. Applying maximum variation sampling, the third party was instructed to choose approximately equal number of participants from upper years and lower years of study and to also represent as many engineering disciplines as possible. This selection strategy was used to obtain students with a range of different engineering education curriculums and experiences which helped focus on the larger general student perspective on engineering creativity instead of being centralized around a specific discipline or year of study [81]. Students were offered a $15 gift certificate to participate in the interviews. This value was selected to encourage students to participate in the interview phase of the study without affecting their incentive to answer questions honestly [81].
3.3.2 Instruments

3.3.2.1 Survey Development

The survey used to measure engineering student attitudes towards creativity was adapted from an instrument developed by Basadur and Hausdorf [45]. Their instrument was designed for large business organizations to measure their employees’ attitudes towards creative thinking, particularly emphasizing the divergent thinking component of creativity. Their instrument contains 18 items and uses a 5-point Likert scale (Strongly Disagree, Disagree, Neutral, Agree, Strongly Agree). The psychometric analysis of this instrument identified the following three factors:

1. Valuing new ideas.
2. Creative individual stereotypes.
3. Too busy for new ideas.

These factors were measured by 11, 3, and 4 items respectively. Test-retest coefficients for these factors were .58, .63, and .61 respectively. Cronbach’s $\alpha$ computed for these factors were .76, .76, and .64 for the business student sample of the revised administration of the survey. Cronbach’s $\alpha$ is used as an estimate for the reliability of the measurement instrument. Items on the survey were adapted for an engineering education context when necessary and two extra items were included unique to engineering creativity attitudes. Survey items can be found in Appendix C.

Divergent thinking is of interest because it is often cited as a difficult aspect for applying creativity by engineering students. Though research has recognized that engineering creativity has elements of both convergent and divergent thinking, it is the latter that tend to be challenging for engineering students, especially for senior students who have difficulty developing novel ideas and suffer from fixation [32] [16]. Furthermore, attitudes towards value, stereotype, and time
were measured because they relate to common barriers to creativity in engineering education such as motivation (based on expectancy-value theory), open mindedness, and iterative idea incubation [32] [82].

Students were also asked for information to group them on levels of the independent variables. The survey asked students to indicate their gender, year of study, and engineering discipline. Additionally, they were asked to indicate their preference for open-ended or closed ended-problem solving using a sliding scale with increments of 10 with Preference for “Closed-Ended Problems with a Single Correct Answer” anchored at 0 and “Open-Ended Problem Solving with Multiple Correct Answers” anchored at 100. Similarly, students were asked to self-report their confidence in engineering creative ability on a sliding scale with anchors of “No Confidence” and “Complete Confidence”. See Appendix C for survey items. These independent variables were gathered for comparison by group level and for any interactions as they have been shown to have an impact on creativity in education contexts [54].

Open-ended survey items were developed to elaborate on the attitudes being measured by the survey and to obtain a general description of creativity environment they experience. Students were asked questions regarding their motivation to be creative in their engineering course work and barriers they experience when trying to be creative. Students were also asked to clarify their definition of engineering creativity and to describe where and how they apply their creative process. These questions were meant to gather data on the general trends of the perceived creativity environment in undergraduate engineering education and for data triangulation from multiple data sources to increase trustworthiness [81]. Accordingly, open-ended survey questions were designed to support the interview questions.
3.3.2.2 Interview Protocol Development

The interview protocol was developed to maximize trustworthiness and elicit in-depth reflection on experiences, understandings, and attitudes towards engineering creativity. The protocol included an general introduction reminding the students of the voluntary and confidential nature of the study to encourage honest and detailed responses [81]. I employed a semi-structured format for the interviews to allow participants to respond freely to questions and to provide as much detail as they saw fit. This enabled me to ask probing questions to glean the details and peculiarities of each participant’s unique response. The semi-structured interviews also permitted gathering of valuable data that was not initially anticipated, as well as shifting between question order in reaction to the content of each response [72].

The contents of interview questions were developed to answer both of the study’s research questions using Kazerounian and Foley’s 10 Maxims for Creativity in Education in Chapter 2 [32] [82]. The Ten Maxims for Creativity were used to extract information on the creativity environment experienced by undergraduate engineering students. Questions were phrased in consideration of the social constructivist philosophy and interpretivist approach adopted for this study in order to focus on how individuals perceive, describe, and make sense of creativity in their engineering education without [75] [77]. This approach enhanced the trustworthiness and authenticity of data collection process [81]. A total of 13 questions were developed to guide the interview. The questions, their purpose and relation to the research questions, and the relevant maxims are shown in Table 4.

38
| Question                                                                                                                                                                                                 | Relevant Research Questions and Purpose                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Relevant Maxims |
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<table>
<thead>
<tr>
<th>Question</th>
<th>Relevant Research Questions and Purpose</th>
<th>Relevant Maxims</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Do you feel creativity can be taught and learned?</td>
<td>EXPERIENCE – UNDERSTANDING – ATTITUDE – To learn about the mentality students have towards being taught and learning creativity skills and to clarify their definition of creativity.</td>
<td>1,5,6,8,10</td>
</tr>
<tr>
<td>10. What challenges (if any) do you experience when asked to apply creative thinking?</td>
<td>EXPERIENCE – To learn about the challenges students experience with creativity expectations in their engineering education.</td>
<td>1-4,6-7,9-10</td>
</tr>
<tr>
<td>11. Can you describe the physical environment when you are working on engineering tasks that require creativity?</td>
<td>EXPERIENCE – To get a sense of the physical environment they prefer when trying to be creative.</td>
<td>1,3,10</td>
</tr>
<tr>
<td>12. How does group work impact your approach to creativity?</td>
<td>EXPERIENCE – To understand how group work impacts student attitudes towards creativity.</td>
<td>1-4,6,8,9-10</td>
</tr>
<tr>
<td>13. (a) If you were to think about creativity as something that is useful, functional, and unobvious, does it differ from your perception of creativity?</td>
<td>UNDERSTANDING – To see how their understanding of creativity differs from a standardized definition of creativity in the engineering context.</td>
<td>1,8</td>
</tr>
</tbody>
</table>

It is important to note that the relevant maxims have been broadly associated with the interview questions. When using qualitative inquiry, crossover of content and themes between questions is expected due to the semi-structured nature of the interviews and the exploratory research approach. The purpose of these interview questions was to promote rich descriptions of the creativity environment and to evoke memories, feelings, and detailed understandings of creativity in undergraduate engineering. Recognition of the complexities of this environment were embodied throughout the qualitative phase of this study.

### 3.3.3 Data Collection

#### 3.3.3.1 Online Survey

Before commencing data collection, ethical approval was required from the General Research Ethics Board (GREB) at Queen’s University. Clearance documentation from GREB and The Tri-
Council Policy Statement: Ethical Conduct for Research Involving Humans Course on Research Ethics (TCPS 2: CORE) certificate can be seen in Appendix A. A Letter of Information for the survey was included on the first page of the survey and it was noted that submission of the survey was considered consent for the data to be used in the study. To ensure confidentiality of the participants’ identities, survey data was collected anonymously. Any identifying information collected for potential interview volunteers was not associated to the survey responses.

Queen’s University undergraduate engineering students from all years of study and disciplines were invited to participate in the survey. The survey was released in Week 2 online using FluidSurveys in the winter semester of 2016. Survey participant recruitment occurred by identifying core engineering classes for each engineering year and discipline and contacting the professors to request time to administer the survey in class or promote the research study. When granted permission to administer the survey, students were instructed to complete the survey online or on paper surveys I had brought to the class. Students were informed they were not obligated to complete the survey. When given permission to promote the survey to the students, I described the purpose of my research and asked the professor to forward an email with the survey link to the students. The survey was also promoted through Queen’s Engineering social media.

Response rates were analyzed after the first three weeks and the remaining time was dedicated to stratifying the sample as needed based response rates. Classes with the appropriate students were identified and instructors of these courses were contacted for permission to administer the survey during class time. Survey data was stored on a password protected computer, and imported or transcribed into Excel for data clean up and IBM SPSS Version 22 for analysis.
3.3.3.2 One-on-one Interviews

Students who were selected to participate interviews were emailed the Letter of Information for the interview and to set up an interview time that was convenient for them. One-on-one interviews were conducted on Queen’s University campus in ILC study rooms. This setting was chosen to improve trustworthiness of the data as these rooms are a familiar and comfortable setting for engineering students [81]. Before beginning the interviews, research participants were given the Letter of Information for the and asked to sign the Letter of Consent. See Appendix C for both Letters of Information and Letter of Consent.

A total of 11 students participated in interviews during the winter semester of 2016, as Creswell recommends interviewing between five and 25 individuals to achieve data saturation for a phenomenological inquiry [72]. Interviews were audio recorded to ensure accuracy of data collection and later transcribed into NVivo Version 11 for analysis. To ensure interviewee confidentiality, students who participated in one-on-one interviews have been assigned pseudonyms.
Chapter 4

Research Analysis

4.1 Data Clean Up and Preparation

4.1.1 Survey Data Clean Up

Before data analysis began, it was necessary to organize the data and clean up missing and erroneous information. A total of 591 survey responses were received from both online and paper survey submissions. For initial data clean up, participants’ responses were removed if less than 85% of the items were completed or if survey respondents did not indicate their gender, year of study, and engineering discipline. This resulted in 504 submissions that were used in the analysis and a return rate of 17.1% based on a total of 2,946 undergraduate engineering students at the beginning of the 2015-16 academic year [79].

For the purposes of data analysis, students who identified being in Year 5+ were grouped with Year 4 students because all of these students have approximately the same level of experience in upper year engineering courses. This was done to proportionally stratify the sample based on year of study. First year students who identified as being in a specific engineering discipline had their discipline responses changed to “Undeclared” because these students have not had exposure to their discipline specific courses at the time the survey was administered. Engineering disciplines were grouped together to reduce the number of group levels. Disciplines were grouped to investigate differences between core engineering disciplines and specialized disciplines in order to answer Research Questions 3. “Chemical” consists of chemical engineering and engineering chemistry, “Mechanical” consists of mechanical and materials engineering only, “Civil” consists of civil engineering only, “Electrical” consists of electrical engineering and computing
engineering, and “Specialized” consists of geological engineering, engineering physics, mathematics engineering, and mining engineering. The analysis was performed on individual disciplines and several combinations of disciplines based on similarity of subject. No significant differences were found for any of these combinations. Before grouping participants, descriptive statistics were calculated for each item including mean, standard deviation, skewness, and kurtosis. Responses for preference and confidence were grouped into three categories to reflect the general attitudes of students: (a) “Negative” (<50), (b) “Neutral” (=50), and (c) “Positive” (>50).

4.1.2 Survey Response Rates
Frequency distributions for each grouping variable were calculated and are shown in Table 4. For gender, male responses ($n = 314$) were greater than females ($n = 190$) which was expected because of male dominated engineering programs. Third year students responded the most ($n = 152$) and fourth year students responded the least ($n = 108$). Chemical engineering ($n = 108$) had the largest discipline representation and mathematics engineering ($n = 4$) and mining engineering ($n = 5$) had the least. For problem preference, most students indicated that they preferred solving open-ended problems ($n = 257$) and an overwhelming majority of students reported having confidence in their creative ability ($n = 415$). Note there were 3 missing responses from the Confidence variable and Preference was missing 2 responses.
### Table 5: Frequencies of responses for each group variable

<table>
<thead>
<tr>
<th>Group Variable</th>
<th>Group Level</th>
<th>n</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>314</td>
<td>62.3</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>190</td>
<td>37.7</td>
</tr>
<tr>
<td>Year of Study</td>
<td>Year 1</td>
<td>113</td>
<td>22.4</td>
</tr>
<tr>
<td></td>
<td>Year 2</td>
<td>131</td>
<td>26.0</td>
</tr>
<tr>
<td></td>
<td>Year 3</td>
<td>152</td>
<td>30.2</td>
</tr>
<tr>
<td></td>
<td>Year 4+</td>
<td>108</td>
<td>21.4</td>
</tr>
<tr>
<td>Engineering Discipline</td>
<td>Chemical Engineering</td>
<td>108</td>
<td>21.4</td>
</tr>
<tr>
<td></td>
<td>Civil Engineering</td>
<td>16</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Electrical Engineering</td>
<td>32</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>Geological Engineering</td>
<td>65</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>Electrical and Computing Engineering</td>
<td>22</td>
<td>4.4</td>
</tr>
<tr>
<td></td>
<td>Engineering Chemistry</td>
<td>18</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>Engineering Physics</td>
<td>57</td>
<td>11.3</td>
</tr>
<tr>
<td></td>
<td>Mathematics and Engineering</td>
<td>4</td>
<td>0.8</td>
</tr>
<tr>
<td></td>
<td>Mechanical and Materials Engineering</td>
<td>73</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>Mining Engineering</td>
<td>5</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Undeclared</td>
<td>104</td>
<td>20.6</td>
</tr>
<tr>
<td>Preference for Open-ended Problem Solving</td>
<td>Negative</td>
<td>160</td>
<td>31.9</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>85</td>
<td>16.9</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>257</td>
<td>51.2</td>
</tr>
<tr>
<td>Confidence in Creative Ability</td>
<td>Negative</td>
<td>60</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>26</td>
<td>5.2</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>415</td>
<td>82.8</td>
</tr>
</tbody>
</table>

### 4.2 Quantitative Analysis

#### 4.2.1 Exploratory Factor Analysis

Exploratory factor analysis was used to identify clusters of variables that represent latent constructs and to determine if the underlying factors identified by Basadur and Hausdorf were present in this adaptation of the survey [45]. Factor analysis is useful for combining survey items that are measuring the same construct, allowing for analysis to be completed at the factor level.
instead of the item level. This was necessary to identify the different attitude to answer Research Question #1 and its associated sub-questions. For exploratory factor analysis, Ford, MacCallum, and Tait recommend that “it is more sensible to rotate the factors obliquely and then determine the tenability of the orthogonality assumption” [pp. 306, 283]. As such, I performed the analysis with the assumption that factors were correlated.

Principal axis extraction was used in the factor analysis because this is a preferred method for non-random sampling [70]. Direct oblimin rotation was used because this is a preferred method for oblique rotations when sample sizes are not too large [70]. The ratio of responses to items was 25.2:1. Factor loadings of less than .31 were supressed as they only account for approximately 10% of the variance. Factors with eigenvalues greater than one were retained in the analysis [84]. Additionally, a scree plot was also used to corroborate the number of factors by visual identification of the inflection point [70].

Performing the initial factor analysis with an oblique rotation on all survey items generated five factors that accounted for 50.20% of the variance. The pattern matrix resulted in a complex structure where all items loaded onto a single factor except for “I really enjoy the challenge of finding a different way to solve a problem” which was double loading. Double loading occurs when more than one items accounts for a large portion of the variance in responses. The items of “The instructor’s idea is usually the best since it comes from a much broader perspective” and “All people have creative ideas from time to time” did not load onto any of the factors. The only item that loaded onto the fifth factor was “Creativity is primarily useful for large engineering projects.” For the initial complex structure, see Table 32 in Appendix D. From the scree plot in Figure 8 in Appendix D, it was difficult to identify a clear inflection point which is the point on
the plot where there is a drastic change in slope, indicating extra factors account for minimal variance in the responses.

Both of the non-loading items were removed for the second iteration of the factor analysis. This resulted in a five factor complex structure accounting for 54.01% of the variance. The items of “Creative ideas seldom work out” and “I really enjoy the challenge of finding a different way to solve a problem” were double loading and “Creativity is primarily useful for large engineering projects” was the only item loading onto the fifth factor. Because factors with less than three items are weak and unstable measures of a latent variable, this item was also removed from subsequent analysis [85].

After removing double loading items, the third iteration resulted in a simple structure and can be seen in Table 6. The analysis resulted in four factors accounting for 50.06% of the variance and a Kaiser-Meyer-Oklin value of .80, above the recommended value of .60, indicating enough responses were collected to have confidence in the factor analysis results [86]. The scree plot also showed four factors accounting for large variance before leveling off with additional factors which can be seen in Figure 3. Before proceeding with the analysis, the factor correlation matrix in Table 7 was analyzed to determine the strength of the assumption that factors measured by the survey were correlated.
### Table 6: Simple structure for oblique rotation factor analysis

<table>
<thead>
<tr>
<th>Items</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creativity is an important skill for engineers.</td>
<td>-.543</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I really enjoy the challenge of finding a different way to solve a problem.</td>
<td>-.469</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>During group work, the team members should encourage creative ideas by demonstrating</td>
<td>-.467</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>When I get a new idea, I really get excited.</td>
<td>-.451</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Engineers can become significantly more creative by learning creative thinking techniques.</td>
<td>-.437</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Crazy sounding ideas can lead to something.</td>
<td>-.393</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Effort in developing good creative ideas is fundamental to decision making, and as such should not be taken for granted.</td>
<td>-.375</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Creative people generally seem to have scrambled minds.</td>
<td></td>
<td>.728</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Really creative people are never very organized.</td>
<td></td>
<td>.641</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Truly creative people also have unusual lifestyles.</td>
<td></td>
<td>.573</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Creative ideas seldom work out.</td>
<td></td>
<td>.321</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I don’t have much time for creativity. I’m too busy just getting my course work done.</td>
<td></td>
<td></td>
<td>.907</td>
<td>-</td>
</tr>
<tr>
<td>I don’t have time to be creative. I’ve got too much to do with my extra curricular commitments.</td>
<td></td>
<td></td>
<td>.737</td>
<td>-</td>
</tr>
<tr>
<td>In my engineering course work, I find it more valuable to get the task done quickly than taking the extra time to be creative.</td>
<td></td>
<td></td>
<td>.412</td>
<td>-</td>
</tr>
<tr>
<td>Only smart, knowledgeable people have good creative ideas.</td>
<td></td>
<td></td>
<td></td>
<td>.620</td>
</tr>
<tr>
<td>Listening to other people’s creative ideas is a waste of time.</td>
<td></td>
<td></td>
<td></td>
<td>.532</td>
</tr>
<tr>
<td>If everyone is providing ideas, no one gets any work done.</td>
<td></td>
<td></td>
<td></td>
<td>.490</td>
</tr>
</tbody>
</table>
Figure 3: Scree plot for initial simple structure of oblique rotation factor analysis

Table 7: Factor correlation matrix

<table>
<thead>
<tr>
<th>Factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>0.04</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.26</td>
<td>0.28</td>
<td>1.00</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>0.36</td>
<td>0.25</td>
<td>0.36</td>
<td>1.00</td>
</tr>
</tbody>
</table>

From the factor correlation matrix, it can be seen that the correlations between the factors were not strong. Based on these results, the correlated factors assumption was negated requiring a factor analysis with orthogonal rotations.
The following factor analysis used the same extraction method, but used varimax orthogonal rotation with all other analysis conditions being the same as the initial factor analysis. The first iteration resulted in a complex structure with five factors accounting for 50.20% of the variability as seen in Table 33 in Appendix D. There were three double loading items including “I really enjoy the challenge of finding a different way to solve a problem”, “Creative ideas seldom workout”, and “Listening to other people’s creative ideas is a waste of time.” The items of “The instructor’s idea is usually the best since it comes from a much broader perspective” and “All people have creative ideas from time to time” did not load onto any of the factors. “Creativity is primarily useful for large engineering projects” was the only item loading onto Factor 5.

The items that were not loading onto any factors and the only item loading onto Factor 5 were removed and the factor analysis was performed again. This resulted in a total of four factors accounting for 50.06% of the variability. For this analysis, all items were single loading except for “I really enjoy the challenge of finding a different way to solve a problem”, “Creative ideas seldom workout”, and “Listening to other people’s creative ideas is a waste of time.” For the next iteration, only “Creative ideas seldom workout was removed because both its loading values were close to the threshold value of .31.

The result of the third iteration indicated four factors accounting for 50.76% of the variability. The item of “Listening to other people’s creative ideas is a waste of time” was still double loading on the first and fourth factors. Considering that the first factor had eight items and the fourth factor was being measured by three factors, removal of this item would have caused the fourth factor to have two associated items which is too small for construct measurement. Therefore, the items of “Only smart, knowledgeable people have good creative ideas” and “If
everyone is providing ideas, no one gets any work done” were removed for the next factor analysis iteration.

The final iteration of the orthogonal factor analysis resulted in a simple structure with three factors accounting for 48.93% of the variability and a Kaiser-Meyer-Olkin value of .75. The negative loading item was posed in the opposite connotation to all other items and required reversing the scale before using the item to determine average factor values. The simple structure factor analysis can be seen in Table 8. The scree plot, seen in Figure 4, for this factor analysis iteration indicated a clear inflection point, confirming the presence of three factors.

Table 8: Simple structure for orthogonal rotation factor analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Creativity is an important skill for engineers.</td>
<td>.597</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Crazy sounding ideas can lead to something.</td>
<td>.539</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Listening to other people’s creative ideas is a waste of time</td>
<td>-.528</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I really enjoy the challenge of finding a different way to solve a problem.</td>
<td>.482</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>When I get a new idea, I really get excited.</td>
<td>.468</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Effort in developing good creative ideas is fundamental to decision making, and as such should not be taken for granted.</td>
<td>.417</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>During group work, the team members should encourage creative ideas by demonstrating</td>
<td>.385</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Engineers can become significantly more creative by learning creative thinking techniques.</td>
<td>.387</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>I don’t have much time for creativity. I’m too busy just getting my course work done.</td>
<td>-</td>
<td>.862</td>
<td>-</td>
</tr>
<tr>
<td>I don’t have time to be creative. I’ve got too much to do with my extra curricular commitments.</td>
<td>-</td>
<td>.730</td>
<td>-</td>
</tr>
<tr>
<td>In my engineering course work, I find it more valuable to get the task done quickly than taking the extra time to be creative.</td>
<td>-</td>
<td>.418</td>
<td>-</td>
</tr>
<tr>
<td>Really creative people are never very organized.</td>
<td>-</td>
<td>-</td>
<td>.685</td>
</tr>
<tr>
<td>Creative people generally seem to have scrambled minds.</td>
<td>-</td>
<td>-</td>
<td>.681</td>
</tr>
<tr>
<td>Truly creative people also have unusual lifestyles.</td>
<td>-</td>
<td>-</td>
<td>.542</td>
</tr>
</tbody>
</table>
Figure 4: Scree plot for initial simple structure of orthogonal rotation factor analysis

The exploratory factor analysis with orthogonal rotation resulted in a simple structure and confirmed the factors being measured by the survey developed by Basadur and Hausdorf. These factors were named according to the nature of the construct that it was measuring and Cronbach’s $\alpha$ values were calculated to estimate internal-consistency of the scale being used. These results are presented in Table 9.

Table 9: Reliability estimates for each factor

<table>
<thead>
<tr>
<th>Factor Number</th>
<th>Factor Name</th>
<th>Number of Items</th>
<th>Cronbach’s $\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Value for Creativity</td>
<td>7</td>
<td>.69</td>
</tr>
<tr>
<td>2</td>
<td>Time for Creativity</td>
<td>3</td>
<td>.71</td>
</tr>
<tr>
<td>3</td>
<td>Creativity Stereotypes</td>
<td>3</td>
<td>.66</td>
</tr>
</tbody>
</table>
For “Value for Creativity” $\alpha = .69$, for “Time for Creativity” $\alpha = .71$, and for “Creativity Stereotypes” $\alpha = .66$. Other than “Time for Creativity”, the Cronbach’s $\alpha$ values were below the recommended .70 [87]. These internal consistency results mean caution should be taken when interpreting the results because of limitations with the instrument. Nonetheless, inferential statistics were performed using these factors. Factors means were calculated using respective items scores with equal weightings for all items. The descriptive statistics for these factors are presented in Table 10 without categorization based on independent variables.

<table>
<thead>
<tr>
<th>Factor</th>
<th>$n$</th>
<th>$\bar{x}$</th>
<th>$s$</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value for Creativity</td>
<td>504</td>
<td>4.21</td>
<td>0.41</td>
<td>-0.79</td>
<td>2.62</td>
</tr>
<tr>
<td>Time for Creativity</td>
<td>504</td>
<td>2.89</td>
<td>0.84</td>
<td>0.05</td>
<td>-0.35</td>
</tr>
<tr>
<td>Creativity Stereotypes</td>
<td>504</td>
<td>2.69</td>
<td>0.71</td>
<td>0.17</td>
<td>-0.16</td>
</tr>
</tbody>
</table>

These results indicate that the survey respondent generally had a high value for creativity in engineering with small variability. In terms of Time for Creativity, average responses were close to neutral with larger variability. On average students tended to slightly disagree with typical creativity stereotypes with a large variability.

4.2.2 Factor 1 – Value for Creativity

The descriptive statistics for Factor 1 based on the different independent variables can be seen in Table 11. Mean values close to 5 indicated a high value for creativity. Levene’s Test for homogeneity of variance was carried out for each test group to validate the assumption of equal variance for both $t$-test and one-way ANOVAs [70]. All tests were not significant except for Confidence, indicating that for this variable the results need to be considered with caution.
Table 11: Descriptive Statistics for Factor 1 – Value for Creativity

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Group Levels</th>
<th>n</th>
<th>$\bar{x}$</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>314</td>
<td>4.20</td>
<td>.41</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>190</td>
<td>4.23</td>
<td>.41</td>
</tr>
<tr>
<td>Year of Study</td>
<td>Year 1</td>
<td>113</td>
<td>4.24</td>
<td>.37</td>
</tr>
<tr>
<td></td>
<td>Year 2</td>
<td>131</td>
<td>4.24</td>
<td>.41</td>
</tr>
<tr>
<td></td>
<td>Year 3</td>
<td>152</td>
<td>4.23</td>
<td>.38</td>
</tr>
<tr>
<td></td>
<td>Year 4+</td>
<td>108</td>
<td>4.10</td>
<td>.47</td>
</tr>
<tr>
<td>Engineering Discipline</td>
<td>Chemistry</td>
<td>126</td>
<td>4.20</td>
<td>.38</td>
</tr>
<tr>
<td></td>
<td>Civil</td>
<td>54</td>
<td>4.17</td>
<td>.57</td>
</tr>
<tr>
<td></td>
<td>Electrical</td>
<td>16</td>
<td>4.18</td>
<td>.32</td>
</tr>
<tr>
<td></td>
<td>Mechanical</td>
<td>73</td>
<td>4.19</td>
<td>.45</td>
</tr>
<tr>
<td></td>
<td>Specialized</td>
<td>131</td>
<td>4.23</td>
<td>.37</td>
</tr>
<tr>
<td>Preference</td>
<td>Negative</td>
<td>160</td>
<td>4.09</td>
<td>.40</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>85</td>
<td>4.05</td>
<td>.43</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>257</td>
<td>4.34</td>
<td>.36</td>
</tr>
<tr>
<td>Confidence</td>
<td>Negative</td>
<td>60</td>
<td>4.10</td>
<td>.40</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>26</td>
<td>3.75</td>
<td>.62</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>415</td>
<td>4.26</td>
<td>.37</td>
</tr>
</tbody>
</table>

An independent sample $t$-test was conducted to determine group differences between gender, $t(502) = -.80, p > .05$. There was no significant difference for between males and females. One-way ANOVAs were completed for the other test groups and results can be seen in Table 12. For Factor 1 – Value for Creativity, there were significant differences between Year of Study, Preference, and Confidence.

Table 13 shows the post-hoc testing results used to determine where the group differences were. The results indicated that Year 4+ students had statistically significant less value for creativity than students of all other years of study. However, the effect size of this finding was small.
Positive preference for open-ended problems had statistically significant more value for creativity than students who were neutral or preferred closed-ended problems. Having high confidence in creative skills also meant that value for creativity was higher. Both of these findings had medium to large effect size.

Table 12: One-way ANOVA results for each independent variable for Factor 1 – Value for Creativity

<table>
<thead>
<tr>
<th>Test Group</th>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>η²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of Study</td>
<td>Between Groups</td>
<td>3</td>
<td>3.15</td>
<td>.025*</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Discipline</td>
<td>Between Groups</td>
<td>4</td>
<td>.256</td>
<td>.906</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>395</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preference</td>
<td>Between Groups</td>
<td>2</td>
<td>30.32</td>
<td>.001*</td>
<td>.108</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>499</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td>Between Groups</td>
<td>2</td>
<td>24.05</td>
<td>.001*</td>
<td>.088</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>498</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13: Post-hoc testing results for Factor 1 – Value for Creativity

<table>
<thead>
<tr>
<th>Base Group</th>
<th>Comparison Group</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 4+</td>
<td>Year 1</td>
<td>.01*</td>
</tr>
<tr>
<td></td>
<td>Year 2</td>
<td>.01*</td>
</tr>
<tr>
<td></td>
<td>Year 3</td>
<td>.01*</td>
</tr>
<tr>
<td>Confidence Positive</td>
<td>Confidence Negative</td>
<td>.003*</td>
</tr>
<tr>
<td></td>
<td>Confidence Neutral</td>
<td>.001*</td>
</tr>
<tr>
<td>Confidence Negative</td>
<td>Confidence Neutral</td>
<td>.001*</td>
</tr>
<tr>
<td>Preference Positive</td>
<td>Preference Negative</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>Preference Neutral</td>
<td>.001*</td>
</tr>
<tr>
<td>Preference Negative</td>
<td>Preference Neutral</td>
<td>.504</td>
</tr>
</tbody>
</table>
4.2.3 Factor 2 – Time for Creativity

The descriptive statistics for Factor 2 – Time for Creativity can be seen in Table 14. Overall, students slightly disagreed that they did not have time to be creative. Levene’s Test for homogeneity of variance yielded not significant differences for any test groups meaning the variance assumption for one-way ANOVA was met.

Table 14: Descriptive Statistics for Factor 2 – Time for Creativity

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Group Levels</th>
<th>n</th>
<th>$\bar{x}$</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>314</td>
<td>2.93</td>
<td>.82</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>190</td>
<td>2.82</td>
<td>.86</td>
</tr>
<tr>
<td>Year of Study</td>
<td>Year 1</td>
<td>113</td>
<td>2.81</td>
<td>.83</td>
</tr>
<tr>
<td></td>
<td>Year 2</td>
<td>131</td>
<td>2.85</td>
<td>.82</td>
</tr>
<tr>
<td></td>
<td>Year 3</td>
<td>152</td>
<td>2.94</td>
<td>.77</td>
</tr>
<tr>
<td></td>
<td>Year 4+</td>
<td>108</td>
<td>2.94</td>
<td>.94</td>
</tr>
<tr>
<td>Engineering Discipline</td>
<td>Chemistry</td>
<td>126</td>
<td>2.92</td>
<td>.77</td>
</tr>
<tr>
<td></td>
<td>Civil</td>
<td>54</td>
<td>3.10</td>
<td>.93</td>
</tr>
<tr>
<td></td>
<td>Electrical</td>
<td>16</td>
<td>2.73</td>
<td>.74</td>
</tr>
<tr>
<td></td>
<td>Mechanical</td>
<td>73</td>
<td>2.89</td>
<td>.92</td>
</tr>
<tr>
<td></td>
<td>Specialized</td>
<td>131</td>
<td>2.83</td>
<td>.79</td>
</tr>
<tr>
<td>Preference</td>
<td>Negative</td>
<td>160</td>
<td>3.10</td>
<td>.81</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>85</td>
<td>2.90</td>
<td>.79</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>257</td>
<td>2.75</td>
<td>.84</td>
</tr>
<tr>
<td>Confidence</td>
<td>Negative</td>
<td>60</td>
<td>3.47</td>
<td>.77</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>26</td>
<td>3.12</td>
<td>.85</td>
</tr>
<tr>
<td></td>
<td>Positive</td>
<td>415</td>
<td>2.79</td>
<td>.81</td>
</tr>
</tbody>
</table>

An independent sample $t$-test was conducted to determine group differences between gender, $t(502) = 1.40, p > .05$ ($p = .01$). There was no significant difference based on gender. One-way ANOVAs were completed for the other test groups and results can be seen in Table 15. For Factor 2 – Time for Creativity, there were significant differences between Preference and Confidence only.
Table 16 shows the post-hoc testing results to determine the group differences. Those who expressed preference for solving open-ended problems felt that they were less impacted by time constraints than students who indicated preference for solving closed-ended problems with a small to medium effect size. Similarly, the results indicate that those with high confidence in their creativity skills felt that they had more time for creativity than students with low confidence, with a medium effect size.

**Table 15: One-way ANOVA results for each independent variable for Factor 2 – Time for Creativity**

<table>
<thead>
<tr>
<th>Test Group</th>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>p</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of Study</td>
<td>Between Groups</td>
<td>3</td>
<td>.771</td>
<td>.511</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td>Between Groups</td>
<td>4</td>
<td>1.175</td>
<td>.321</td>
<td>-</td>
</tr>
<tr>
<td>Discipline</td>
<td>Within Groups</td>
<td>395</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preference</td>
<td>Between Groups</td>
<td>2</td>
<td>9.03</td>
<td>.001*</td>
<td>.035</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>499</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td>Between Groups</td>
<td>2</td>
<td>20.30</td>
<td>.001*</td>
<td>.075</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>498</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 16: Post-hoc testing results for Factor 2 – Time for Creativity**

<table>
<thead>
<tr>
<th>Base Group</th>
<th>Comparison Group</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confidence Positive</td>
<td>Confidence Negative</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>Confidence Neutral</td>
<td>.059</td>
</tr>
<tr>
<td>Confidence Negative</td>
<td>Confidence Neutral</td>
<td>.105</td>
</tr>
<tr>
<td>Preference Positive</td>
<td>Preference Negative</td>
<td>.001*</td>
</tr>
<tr>
<td></td>
<td>Preference Neutral</td>
<td>.324</td>
</tr>
<tr>
<td>Preference Negative</td>
<td>Preference Neutral</td>
<td>.155</td>
</tr>
</tbody>
</table>
### Table 17: Descriptive Statistics for Factor 3 – Creativity Stereotypes

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Group Levels</th>
<th>n</th>
<th>( \bar{x} )</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Male</td>
<td>314</td>
<td>2.74</td>
<td>.73</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>190</td>
<td>2.59</td>
<td>.68</td>
</tr>
<tr>
<td>Year of Study</td>
<td>Year 1</td>
<td>113</td>
<td>2.69</td>
<td>.78</td>
</tr>
<tr>
<td></td>
<td>Year 2</td>
<td>131</td>
<td>2.72</td>
<td>.66</td>
</tr>
<tr>
<td></td>
<td>Year 3</td>
<td>152</td>
<td>2.68</td>
<td>.68</td>
</tr>
<tr>
<td></td>
<td>Year 4+</td>
<td>108</td>
<td>2.65</td>
<td>.74</td>
</tr>
<tr>
<td>Engineering Discipline</td>
<td>Chemistry</td>
<td>126</td>
<td>2.71</td>
<td>.61</td>
</tr>
<tr>
<td></td>
<td>Civil</td>
<td>54</td>
<td>2.84</td>
<td>.89</td>
</tr>
<tr>
<td></td>
<td>Electrical</td>
<td>16</td>
<td>2.42</td>
<td>.74</td>
</tr>
<tr>
<td></td>
<td>Mechanical</td>
<td>73</td>
<td>2.73</td>
<td>.69</td>
</tr>
<tr>
<td></td>
<td>Specialized</td>
<td>131</td>
<td>2.62</td>
<td>.70</td>
</tr>
<tr>
<td>Preference</td>
<td>Positive</td>
<td>257</td>
<td>2.71</td>
<td>.69</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>160</td>
<td>2.68</td>
<td>.77</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>85</td>
<td>2.60</td>
<td>.67</td>
</tr>
<tr>
<td>Confidence</td>
<td>Positive</td>
<td>60</td>
<td>2.83</td>
<td>.75</td>
</tr>
<tr>
<td></td>
<td>Negative</td>
<td>415</td>
<td>2.66</td>
<td>.70</td>
</tr>
<tr>
<td></td>
<td>Neutral</td>
<td>26</td>
<td>2.78</td>
<td>.75</td>
</tr>
</tbody>
</table>

An independent sample \( t \)-test was conducted to determine group differences between gender, \( t(502) = 2.29, p < .05 \) (.022), \( d = .21 \). There was a significant difference based on gender where males identified statistically more with creativity stereotypes than females, however the effect size was small. One-way ANOVAs were completed for the other test groups and results can be seen in Table 18. For Factor 3 – Creativity Stereotypes, there were no significant differences between any of the test groups.
Table 18: One-way ANOVA results for each independent variable

<table>
<thead>
<tr>
<th>Test Group</th>
<th>Source</th>
<th>df</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of Study</td>
<td>Between Groups</td>
<td>3</td>
<td>.094</td>
<td>.906</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td>Between Groups</td>
<td>4</td>
<td>1.602</td>
<td>.173</td>
</tr>
<tr>
<td>Discipline</td>
<td>Within Groups</td>
<td>395</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preference</td>
<td>Between Groups</td>
<td>2</td>
<td>.731</td>
<td>.482</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>499</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Confidence</td>
<td>Between Groups</td>
<td>2</td>
<td>1.776</td>
<td>.170</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>498</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4.2.5 Nonparametric Testing

Nonparametric testing was conducted to investigate if the assumption of a normal distribution impacted the results from the t-tests and one-way ANOVAs. The Mann-Whitney U test was used instead of the t-test for nonparametric inferential statistics when comparing exactly two groups (gender). The Kruskal-Wallis H Test was used in place of one-way ANOVA when comparing more than two groups (year of study, engineering discipline, preference, and confidence) [70]. Results from these nonparametric tests identified the same significant differences as the results from parametric statistics.

4.2.6 Open-ended Survey Items Analysis

Analysis of the open-ended survey questions indicated that some items were unnecessary because students repeated the same responses in other questions. Questions 23, 24, and 29 were retained for analysis.

Question 23 asked students to provide their definition of engineering creativity. Qualitative constant comparison analysis, an inductive technique described by Hewitt-Taylor, was used to
develop categories and subsequent themes to emerge. Frequency analysis was then performed on the categories in each theme to indicate the most common definitions of engineering creativity.

The results from this analysis can be seen in Table 19.

**Table 19: Constant comparison and frequency results for engineering creativity definitions (n = 416)**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Category</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Action</td>
<td>Problem Solving</td>
<td>204 (49.0)</td>
</tr>
<tr>
<td></td>
<td>Ideation</td>
<td>152 (36.8)</td>
</tr>
<tr>
<td></td>
<td>Thinking Outside the Box</td>
<td>107 (25.7)</td>
</tr>
<tr>
<td></td>
<td>Critical Thinking</td>
<td>61 (14.7)</td>
</tr>
<tr>
<td></td>
<td>Designing</td>
<td>55 (13.2)</td>
</tr>
<tr>
<td></td>
<td>Modification</td>
<td>46 (11.1)</td>
</tr>
<tr>
<td>Characteristic</td>
<td>Novel</td>
<td>152 (36.5)</td>
</tr>
<tr>
<td></td>
<td>Unique</td>
<td>151 (36.3)</td>
</tr>
<tr>
<td></td>
<td>Unobvious</td>
<td>63 (15.1)</td>
</tr>
<tr>
<td></td>
<td>Functional</td>
<td>58 (13.9)</td>
</tr>
<tr>
<td></td>
<td>Innovative</td>
<td>45 (10.8)</td>
</tr>
<tr>
<td></td>
<td>Improvement</td>
<td>33 (7.9)</td>
</tr>
<tr>
<td></td>
<td>Complex</td>
<td>23 (5.5)</td>
</tr>
<tr>
<td></td>
<td>Simple</td>
<td>18 (4.3)</td>
</tr>
<tr>
<td></td>
<td>Abstract</td>
<td>17 (4.1)</td>
</tr>
</tbody>
</table>

Question 24 asked students to list any courses in which they experienced engineering creativity. Analysis of the survey results indicated that students identified four different types of engineering courses where they have opportunities to be creative. The frequency analysis for each category is displayed in Table 20. Students overwhelmingly identified their engineering design courses, both multi-disciplinary and discipline specific, as courses where they can apply engineering creativity. Programming courses were also mentioned by some students. It is important to note that some students commented that creativity was absent from all of their courses.
Question 29 asked students to list any challenges they experience when trying to be creative. Students identified a variety of barriers that were categorized into common barriers that have been reported in the literature [41] [32]. A frequency analysis of each type of challenge was completed and can be seen in Table 21. The results indicated that time and assessment were the most common perceived barriers to creativity. Lack of opportunity for creativity was also identified by many students as a barrier to engineering creativity. Other less common factors included lack of knowledge and experience with the technical details of engineering, and difficulty with divergent thinking or fixation.

Table 21: Frequency Analysis for Identified Barriers to Creativity (n = 438)

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>149 (34.0)</td>
</tr>
<tr>
<td>Assessment</td>
<td>95 (21.7)</td>
</tr>
<tr>
<td>Lack of Opportunity</td>
<td>91 (20.8)</td>
</tr>
<tr>
<td>Knowledge and Experience</td>
<td>38 (8.7)</td>
</tr>
<tr>
<td>Fixation</td>
<td>29 (6.6)</td>
</tr>
<tr>
<td>Teaching Methods</td>
<td>18 (4.1)</td>
</tr>
<tr>
<td>Group Work</td>
<td>18 (4.1)</td>
</tr>
<tr>
<td>None</td>
<td>14 (3.2)</td>
</tr>
<tr>
<td>Discomfort with Ambiguity</td>
<td>9 (2.1)</td>
</tr>
</tbody>
</table>

4.3 Qualitative Analysis

The qualitative analysis was carried by first transcribing all interviews and importing them into NVivo V11.1.1 for analysis [88]. Research participants were assigned pseudonyms which can be seen in Table 22 along with their gender, year of study, and engineering discipline. Interviews
were read and reread to get close with the data and nuances of the responses. LeCompte’s strategy for analyzing qualitative was used by first coding all the interviews and establishing items [89]. These items were then grouped into categories. From these categories patterns were recognized culminating in emergent themes which are depicted in Figure 5. Five themes emerged:
(a) “Manifestation of Creativity”, (b) “Essence of Engineering Creativity”, (c) “Creativity Expectations” (d) “Motivation for Creativity”, and (e) “Requirements for Creative Success”.
Limitations and discomforts in each theme were threads that surfaced through the analysis.

Table 22: Demographic information of interview participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Gender</th>
<th>Year of Study</th>
<th>Engineering Discipline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stella</td>
<td>Female</td>
<td>1</td>
<td>Undeclared</td>
</tr>
<tr>
<td>Jed</td>
<td>Male</td>
<td>1</td>
<td>Undeclared</td>
</tr>
<tr>
<td>Charlie</td>
<td>Male</td>
<td>1</td>
<td>Undeclared</td>
</tr>
<tr>
<td>Althea</td>
<td>Female</td>
<td>2</td>
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<tr>
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<tr>
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<td>Stephen</td>
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<td>Mechanical</td>
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4.3.1 Manifestation of Creativity

The theme “Manifestation of Creativity” describes situations that provide opportunities for students to be creative in engineering education. Many of the interviewees felt that creativity was not a central focus of the engineering curriculum and was limited to specific courses, subjects, and assignment types. The categories in this theme summarize where students recognized these opportunities for creativity and the activities they believed manifested creativity within engineering. Furthermore, as students were recalling their experiences with engineering creativity, they recognized limitations and discomforts that can be attributed to different activities that students perceived to embody engineering creativity. Table 23 displays the categories, limitations, and discomforts identified in this theme.
The most prominent category in this theme was engineering design. In all of the interviews, when students discussed their experiences with engineering creativity, they often spoke of their experiences with engineering design. The focus on design seemed to be a natural reaction when students were asked questions about engineering creativity because every interview was dominated by discussion on engineering design. When discussing opportunities for creativity with his first year projects, Jed focused on his engineering design course while acknowledging that he did not experience any creativity in his more technical first year courses, “I think over the semester there’s been more room to be creative with these engineering projects. Like I keep going
back to them but I think that it is the be all and end all of creativity in engineering. All the other stuff is just the hard science stuff.”

Rueben felt that creativity applied to the whole design process. “I think that the whole process of taking a problem, evaluating it, thinking of multiple solutions, evaluating the solutions, and that whole feedback loop where each step involves creative thinking, decision-making, and all that is really really important.” When recalling his experiences with creativity in his engineering education, Jack said, “first thought is in the engineering design courses. They focus on creative thinking, and original thinking, and design, obviously.” The association between creativity and engineering design was consistent across all interviews.

While all students identified creativity in engineering design work, different aspects of the engineering design process were emphasized in each interview. The step in the engineering design process that most students felt provided the most opportunity for creativity was in the idea generation phase. When discussing idea generation, students often referred to brainstorming different solutions to open-ended problems and using design tools to enhance creativity. Cherise conveyed her experience with engineering creativity in the form of brainstorming and using design tools in her engineering design courses, “like they kind of try to get you to think more creatively through the different methods of brainstorming and that sort of stuff that they teach us.” Scarlet’s felt that in her design courses, creative was taught in relation to idea generation, “so in design courses I know they talked about it in the sense of idea generation mostly.”

Jack’s experience in his engineering courses was that creativity in engineering meant using design tools to aid with idea generation, “so I guess they discuss brainstorming processes and
idea generation and ways to instill creativity in us and to adopt creativity in our science. Yeah, basically mostly through brainstorming, mind mapping, that kind of stuff.” Similarly, Stephen discussed using idea generation tools in the design process, “they talk a lot about ideation and give a lot of really good, or not really good, but a lot of industry standard methods of ideation.” The practice of brainstorming solutions was a general topic that several students provided in the interviews, however the students had difficulty articulating the brainstorming practice and often associated it with “thinking outside the box.”

Other students focused on aspects of understanding the problem in the engineering design process. The most creative solutions were the ones that addressed the root of the problem, and not taking the design challenge at face value. Cherise felt that because of the open-ended nature of design problems, creativity was required to truly understand the problem, “sometimes you don’t even know what they're asking for and you're just like, ‘how am I supposed to give you an answer when I don't know what the question is?’ So then you have to work to gather information and try to figure it out. So I guess there is some creativity in there.”

Stephen thought that there was creativity in taking a holistic approach to problem solving to help determine where and how the problem can be influenced from an engineering perspective:

“your client or whoever your project manager is, whoever comes to you with a problem and they say what the problem is, what you have to do as an engineer is take six steps back and take a look at the holistic system. And then creativity comes in looking at it and saying where can I influence this problem? From where does this problem originate from? Is there even a problem? What do I need to actually fix? So there's creativity there in trying to think of new ways of looking at the problem, in looking at the way things are done on a larger level to maybe find better solutions. Like instead of treating the symptom, treat the larger systematic problem. The smaller problem that’s immediate is caused by something larger so I think there's definitely a lot of creativity in that aspect... I think the main creativity happens in discovering the problem and discovering the root of the problem because once you know what the actual real problem you need to solve is, it's not necessarily trivial but the really creative solutions come from addressing the really larger level tougher problems.”
In his response, he stressed that problems needed to be complex enough to be solved creatively. Stephen understood that undertaking a more complete evaluation of multifaceted problems, usually led to more creative solutions. However, he did note he did not come to this realization until his senior engineering years.

Althea stated that she thinks breaking down the problem helps with generating creative ideas, but is not the only opportunity for engineering creativity in the design process. She expressed that creativity is difficult because of her style of thinking and problem solving, “thinking outside the box I cannot do. I’m someone that's like, A and B, OK that's how it is. Like find the best idea, that's my mentality. I have to find the best idea first. Instead it should be just like what are some ideas. And instead of looking at it as a big whole thing, break it down into smaller bits.” Similarly, Cassidy commented that, “breaking things down into smaller areas and combining them for a more creative and more varied solution is really emphasized.” The manifestation of engineering creativity in design had implications on perceptions of creativity, particularly with how students define and understand expectations with engineering creativity.

Some students described opportunities for creativity more broadly in the sense that any kind of problem solving required creativity. Being in first year engineering, Stella felt engineering creativity was using tools and methods that were taught in class to approach and solve problems, “creativity in first year engineering I find comes from, ‘OK. Here are the tools and here are the methods that you can use to approach a problem or approach a project.’” Similarly, Rueben recalled that first year engineering emphasized the engineer’s role as a problem solver, “I guess what they always told us in first year is that engineers are problems solvers so I think the idea that there's multiple ways you can solve the problem is really important to engineering.” The
connection between general problem solving and creativity was most evident when students interpreted engineering creativity as solving open-ended problems with multiple correct answers which is discussed in detail in Section 4.3.2.

Another important element of engineering design that students identified as having an impact on the manifestation of engineering creativity was the framing and scope of design problems. In some cases, students explained that the opportunity for creativity in open-ended projects was usually implied through the framing of the design challenge. When discussing creativity in her design projects, Stella said, “it’s more so something that you come to the sense of yourself. They say to come up with an original idea following the guidelines that are given. It’s more so something that you as individual have to interpret yourself.” Similarly, Cherise stated, “they give us more open-ended projects which try to encourage creativity. So they’ll say you need to use this many sensors, and they’ll give you a list of 20 and say to use three. You can make your project anything as long as you incorporate three components. But it's not really outright discussed per say.”

Stella gave an example of how creativity can be affected by the framing of the questions and guidelines:

“For example, in terms of the robot project we have all these sensors that we can work with but maybe you only want to use one. Maybe you only want to use, for example, collision sensors. Unfortunately, that doesn't satisfy the criteria now. If we’re a level C, it’s one sensor. For a level B, use two sensors. For a level A, you need to use three or more sensors. Suddenly your program, it may be very creative in what the solution is, however it doesn't fulfil the criteria needed.”

She pointed out a disconnect between potentially creative solutions and the guidelines given for the project. It’s also important to note her focus on grades, a common concern that many students
expressed when it comes to being creative in engineering. Impacts of assessment are detailed in Section 4.3.3.

Charlie also commented that guidelines can limit creativity, emphasizing the importance of how instructors pose problems, “I think that's the kind of importance of the creative part. Where as if they say, 'all right, your assignment is to write me a report that just says cover these guidelines,' you know there's not very much room for creativity.” Charlie continued to discuss how instructors usually presented the simplest examples of designs when assigning open-ended projects. He explained that giving the simplest example, in this case a robot that follows a maze, set low expectations for the assignment and did not encourage students to take a creative approach:

“like the robot thing, a lot of people do mazes. There’s this one kid who did a really cool thing but like you know a lot of people did mazes kind of thing. So I think if they framed it more so like mazes is the third option in a giant list. But they say someone made a Bop-it, someone made a cruise control function, which is what I did, and people did this and this and this. That would really make you think and that's just the framing of it.”

Though Charlie did acknowledge that risk of replicating examples no matter what they were, he was resolute that creativity needs to be encouraged by proper framing of the problem.

Another common manifestation of creativity in engineering education was the freedom of choice with design projects. Students highlighted different variations of project freedom that gave opportunities for engineering creativity including freedom to choose the specifications of the final design and freedom in the approach to problem solving. Charlie saw creativity in projects where the final design was decided by the students, “graphics was a more structured [project] in that you had to do a project and then design it how you want kind of thing. But still you had to do an MP3 player, or alarm o'clock, or whatever.” Even though he felt that the project allowed him to approach the design any way he wanted, he was limited by the project selection.
Freedom of problem solving approach and freedom to make design decisions was also important aspect discussed in the category of project freedom. Jed consistently emphasized his autonomy to follow his own method when engaging in engineering design projects, “so our project is to design the experiment. So we got the choice of which bio signature we want to look for, why it's important, why it's a good bio signature. We settled on carbonates because it's a good sign of liquid water in history. And we got do our own research and use our own capabilities to design an experiment.” His comments reflected a personal connection to engineering design. Several of the students shared this sentiment where they expressed how they felt a personal investment in their design projects because they more accurately depicted their capabilities as an engineer. On the other hand, following equations to come to a single correct solution did not encompass a personal contribution and was more reflective of their pattern recognition and math skills.

Several of the students pointed out that not all problem solving presented opportunities for creativity. They felt that the manifestation of creativity can only come from open-ended problem solving. When discussing opportunities for creativity, Jed said, “open-ended problems are definitely number one.” Charlie also saw creativity in open-ended projects, “so just like emphasizing that in those open-ended problems there should be an open-ended solution which involves creativity.” Likewise, Stella found creative opportunities in the open-ended projects in her first year of engineering, “of course we were given guidelines on how to use the software, things to look out for, certain modeling techniques, but you were really given free range in the way you modeled the project. The different material you used, the different colours you used, as long as you justified why you used what you used. It was a very open project.” Stella’s response indicated that she felt open-ended problem solving meant freedom of design in functionality and aesthetics.
Many students felt that creativity in engineering came from how much freedom was available within the constraints and guidelines of the project. Charlie explained his experience of creativity in engineering education, “I think it kind of gets you like thinking of applying it a bit more. Like it's a different type of thinking. I'd say it's not so much cookie-cutter, it's more do what you want kind of thing with basic guidelines.” Rueben had a similar experience with creativity, “you have the ability to be creative in these areas and these areas as long as you stay within these constraints.” Bertha expressed an analogous sentiment, “so it kind of gives you the freedom to do whatever you want within limits obviously.” It was common for students to feel that less constraints meant more freedom to be creativity with their designs.

Another key characteristic of problems that provide opportunities for creativity was the complexity and scope. Students explained that problems needed to be complex enough for design tools to be effective, and the scope needed to be large enough so there are enough functional variables to work with. Stephen stated that all of the creative design tools and process that are taught in his design courses are primarily useful for large complex engineering projects, but the nature of the engineering curriculum and workload simplifies the scope of his projects. This makes it difficult to produce a creative design:

“So they discuss brainstorming, and discuss teaming, and discuss SCAMPER, and a lot of these methods that I imagine are really useful when you have a lot of time to devote to a project and you have a fairly complex project. There's a certain scaling down that happens when you try to take a project that really should take every hour over four months or eight months and you try to cram it in with all the other courses.”

Stephen’s insight also shed light to the problem of authentic creativity and not how problems that are scaled down do not provide an authentic learning experience.
Bertha said creativity can be better fostered in engineering students by taking advantage of design opportunities in every course. She emphasized the need to have larger scope problems so there are enough variables so different solutions can be produced for the same problem, “in every single course, even though I'm never going to design a river or dam, in every course there's an applicable design project that could have a larger scope and everyone can design it differently.” Bertha continued to discuss her experience with small scope design projects and how even if there was some opportunity for some creativity, the scope of the projects limited that freedom, “so I’ll talk about my third year design project, which the entire class of civil third year did the same project. And we were all designing the same thing. And you had creative freedom to design but it was a very small scope project and you didn't want to do the same thing as those people. And so you were limited to your creativity of what you could do.” It was clear that her understanding of creativity in engineering meant producing different solutions to the same problem.

Another manifestation of creativity perceived by students was in the application of fundamental scientific knowledge to engineering problems. When commenting on her expectations for creativity in latter engineering education years, Stella envisioned that once students have the necessary foundational knowledge, it will be possible to tackle projects with larger scopes, “I'm hoping that in third and fourth year, now that students have a foundational base in what they need, and the mathematical tools they need, and the scientific tools they need, the scope is much larger in the way that you approach a problem.” These remarks followed up a discussion on the lack of opportunity for creativity in the early years of engineering.

Several participants made the association between engineering creativity and product design, some extending it further by connecting creativity with entrepreneurship. Scarlet felt there was a
strong link between creativity in engineering and product design, “like a lot of the time when we're learning in school, you think about creativity in terms of making a new product, or something related to business that you can sell... I think about in terms of products and less so in terms of science.” She went on to point out how successful businesses are creative, “I think if you look at business too, like creative people who create products or creative processes are the ones that often succeed. If you look at Apple for example. Like the iPod, that's never been done before and someone came up with it and it's wildly successful.” Even as chemical engineering student, Scarlet still associated engineering creativity with product design.

The students who made connections between engineering creativity and entrepreneurship tended to focus on producing designs that have value and address a user need. This was reflected in Jack’s comments, “I think if an engineer could be creative then maybe he or she will think of a better solution or like a cheaper way to do something. I think there’s always ways to make things cheaper, you can always make things stronger and last longer.” Cassidy had a similar understanding, “looking in those design courses we’re told that creativity is important and it's necessary to come up with new solutions that are valuable.” Both of them acknowledged that creative engineering can add value to a solution through economical and functional improvements.

Stemming from the category of product design, some students discussed opportunities for creativity when they were required to generate a working prototype. Stephen continuously made the connection between creativity and prototyping but was frustrated with the lack of emphasis on prototyping in his design courses. When discussing how he used creativity in one his design projects, Stephen said, “it might've been our project was very [hard]. I think we had a fairly
challenging project so it's hard to say when there's no real time to prototype and there's no emphasis on a prototype... It's really easy to draw something on the whiteboard and say this is a really great design but that step that's needed to take it from idea space to real space is in and of itself an entire challenge.” The association of engineering creativity to something physical whether it be a product for users, code for a program, or an actual prototype was common throughout all the interviews.

Many students felt that creativity was manifested through the use of modern technology. CAD software, robots, computer programming, and modern physics were frequently mentioned in the interview responses. Rueben recalled his experiences with creativity in design and programming courses, “I've got a design course this semester where it's spoken about a little bit and I've had some like coding courses where it's spoken about a small amount.” Cherise discussed the opportunity for bonus marks in her programming courses by being creative, “in some of like the coding assignments what they’ll do is they’ll say there's like 10 marks for the actual assignment as is as described and then they'll say if you go above and beyond this and incorporate your own little things you can get up to five bonus marks or something.” In her response, Cherise equated the extra effort with being creative.

Althea mentioned that creativity is useful in programming because of the multiple ways code can be written to execute the same task, “but like when it comes to coding, it's good to have creativity because like one way might not work but one person might find a different way to code it and it works.” Similarly, Jed saw creativity to his course that required writing code for a robot to complete a given task, “the first thing that jumps to mind is our computer programming course. Our year end project is to make any program you want to make the robot do anything.” Stella felt
the same way about her programming courses, “*this semester more so creativity is coming forth in the computer programming courses.*” Coding was recognized by several students as a manifestation of creativity because it had elements of open-ended problem solving as well as modern technology.

4.3.1.1 Limitations

The major limitations with the manifestation of creativity in engineering education were the limited opportunities for demonstrating creativity and the illusion of creativity with some of their engineering projects. Though students were able to recall experiences with engineering creativity and the context of those experiences, most acknowledged that creative opportunities were very limited. The interviews also revealed the concept of the illusion of creativity, meaning students not only feel that they do not have many projects that provide creativity opportunities, but there are some assignments that call for creativity when, in reality, the opportunity to do is not present.

Many students explained that the majority of their courses in engineering are core technical courses which focused on math and using equations for problem solving. Creativity in these courses was not evident to the interviewees. Stephen said, “*in all the kind of theory, science, more rigorous based courses, creativity has been virtually nonexistent.*” Althea described her general perception of engineering education, “*it’s usually pretty cut and dry, like here’s the math, do the math.*” Jack discussed his technical first year engineering courses, “*I guess those don’t really encourage much creativity. With math you’re just solving problems.*”

The problem with emphasis on mastering technical knowledge was particularly evident in the responses of first year engineers. Jed was only able to identify one course where creativity was
present, that being his design course, “I wouldn't say there's too much creativity going on to be frankly honest except in that one course.” Stella had a similar understanding “[creativity] has been really evident in very few courses that you take in first year engineering as most are just core analytical courses.” Bertha noted that taking so many technical courses in the early years of engineering had an impact on her expectations with the rest of the curriculum, “you know you judge a book by its cover. So in first year there was no creativity so I didn't really expect it.” This statement shed light into how students develop impressions of what engineering is early on in their engineering education.

Cassidy noted that even in technical courses there were opportunities for creativity as she related engineering creativity to the general construct of problem solving, “I think like to certain extent there is a huge opportunity for [creativity] in every technical course because it’s all based on problem-solving. Even if they just look at the approach to solving a problem as more of solving a problem and less like this is an assignment question.” She continued to discuss about how she felt that most of her courses promoted mastering a single procedure to solve a specific problem rather than understanding the logic of the problem solving approach. Rueben expressed a similar sentiment, but focused on the lack of opportunity for open-ended problem solving, “now with our design projects and with most of our courses it's pretty limited or it's nonexistent in quite a few of the courses,” and “I think having more open ended projects would be a start. I have like one in a whole year so out of a quarter of my degree having one project where there’s some level of creativity is probably not enough.”
Stephen mentioned that he found being creative difficult in engineering design because none of his projects required bringing a theoretical design to a functional working product. He noted that producing the theoretical design is only one part of bringing a project to fruition:

“I can remember in first year graphics we had a creative design project where we had to use SolidWorks to make a CAD model of something. There was like a little bit of emphasis on being creative in how do you designed it, making it look good, making sure you could put it together. But there wasn't a ton of emphasis on actually manufacturability or being able to take that CAD model, put it into drawings, make those drawings into parts, and then put together the assembly. And it's really easy to draw something on the whiteboard and say this is a really great design but that step that's needed to take it from idea space to real space is in and of itself an entire challenge.”

In this comment, it is clear that Stephen associated engineering creativity to not just the theoretical design process, but he recognized that it is important when solving engineering challenges, many of which arise when trying to go from a theoretical design to functional product. However, the limited opportunity for the prototyping phase of the design process limited the extent to which creativity was present in his projects.

Some students remarked that they felt there was an illusion of creativity in some of their projects and assignments. In this respect, projects were presented as open-ended and students were encouraged to be creative. Yet, in actuality, there was limited space for applying a creative process. Rueben stated, “in the courses where it is existing it would be saying, ‘we want you to be creative in your design with these steps.’ But overall, generally, the whole project there's a set thing that we need to accomplish.” Scarlet had a similar response when discussing her experiences with engineering creativity, pointing out how students do not feel their assignments give opportunities for creativity even if that was the intention, “engineering is being innovative and being creative but when you're taking like a stats course, that's completely not in something like that at all. And maybe professors think that is what assignments are doing and maybe thinking outside the box, but students don’t see it that way.” Her commentary highlighted how
students have predetermined expectations that the purpose of technical courses is to learn how to follow a set procedure which will result in a single correct solution, particularly in math courses.

Rueben explained how the illusion of creativity occurs when problems can actually be simplified to using pattern recognition and application of scientific knowledge, “There are knowledge questions where there’s a question and based on pattern recognition, you should be able to see the answer. That’s probably less effective for creativity.” Stephen’s interpretation was similar where he noted that the more difficult questions usually require a step that may not be obvious, however this should not be considered as creativity because once the step is realized, it becomes repeated pattern recognition, “Sometimes there's a little bit of what a lot of people would call trick questions where there’s something that you have to realize in order to make a logical leap from one part of the solution to the next... And I don't really think that's true creativity because once you see that once, you know to look for it again on an exam.” Stephen continued to describe these questions as, “Rote learning question with fancy dressing.” Cassidy felt the same way, discussing several projects she had experienced in her engineering education, “And there was the veil of creativity on those projects but really ultimately they weren't. They didn't really give an opportunity for completely open-ended thinking and problem solving because you couldn't do that.” These insights illuminated a problem where students lose interest in creativity because their assignments and course work are not aligned with their understandings and definitions of engineering creativity.

Many students expressed that they would like to see more opportunities for creativity in engineering education. Cassidy stated, “I wouldn't even necessarily say focus but I would like more opportunity in these really heavy technical courses for some sort of creative component or
creative thinking or creative process. Something along those lines. Even if they just refer to it. Even if it's just mentioned because it's neglected so badly right now.” Rueben also felt there was not enough opportunity for creativity in his engineering education, “with the engineering courses I'm taking I've been a little disappointed that there's really no creativity.” Throughout the interviews it was common for students to articulate value for creative in engineering and these comments highlighted the desire to have more creativity in the engineering curriculum.

4.3.1.2 Discomfort

The primary discomforts that surfaced from the analysis were related to the engineering design process. The first came from the requirement of writing reports for design projects and the second was related to the nature of designing solutions to open-ended problems. These discomforts originate from experiences prior to entering undergraduate engineering programs, and are not direct symptoms of the engineering program design.

Some students expressed a discomfort with writing reports. Bertha explained how she had a stronger preference for solving problems with physics and math where there is one correct compared to design projects which require written reports, “I actually like the technical math stuff more than I like design projects... I would much rather do 100 math problems than write a five-page essay on why riverbeds erode and different ways of mitigating that.” She partially attributed this feeling to her discomfort writing reports, “I think that that's something that a lot of engineers feel. Communicating in an essay for me is a lot harder than it is to figure out math. And it's a push for me outside my comfort someone when I’m trying to do that.” Her response shed light on how most engineering students are strong in math and science subjects, while their English and writing skills are typically weaker.
Scarlet focused on her lack of experience writing technical reports, “Engineers often think they won’t need to write so when you get to university and you’re writing labs and all these papers, like they are technically based but there is a structure to them, and it's not too different than writing like an English essay. So I think people feel uncomfortable with that because they haven't had the practice writing these technical essays I suppose.” She mentioned that many of her peers went into engineering assuming it was all about solving equations and some of them were overwhelmed when required to solve problems open-ended problems using the design process and documenting how they completed the design.

Some students also exhibited discomfort with trying something new. Bertha explained, “you couldn’t do whatever you wanted because there were so many other people doing exact same thing that you kind of wanted to compete with them to see who could do it better. So you didn't want to try something out on a limb because you know that might not have worked.” She thought that creativity required an element of risk which was difficult to take on when all students were doing the same project, stating, “it's outside my comfort zone.” With identical projects, it was difficult to set yourself apart from the rest of the class and the risk of losing marks made trying something new and creativity was not worth the risk. Charlie described a sense of fear with trying something new, “I'm sure [students] want to be creative but I a lot of the time people get really scared. It's the human nature thing of branching out and trying something new that maybe has not been implemented. I think people are really scared of that.” There was a clear connection between the discomfort with trying something new and the fear of taking risks, both of which help promote a positive creativity environment in engineering education.
4.3.2 Essence of Engineering Creativity

The theme “Essence of Engineering Creativity” details how interview participants interpreted what it meant to be creative in engineering education. Throughout all the interviews, participants discussed their experiences with engineering creativity. Within these experiences, students described their understanding of what engineering creativity was and what creativity entailed in an engineering context. The categories in this theme summarize the ways that creativity was defined by the engineering students and provided insight into the essence of engineering creativity through the perceptions of engineering students. Table 24 outlines the categories for this theme. Within this theme, the underlying threads of Discomfort with Creativity and Limitations to Being Creative were present as students discussed their discomfort with creativity in accordance with their definitions of engineering creativity, as well as some limitations that have arisen based on these characteristics of creativity.

Many students identified doing something novel as being creative. This included creating new solutions, using new methods or procedures, and solving new problems that have not been solved before. The connection of creativity and novelty appeared to be grounded in the concept that being creative is doing something unique. Scarlet described this perception in her definition of engineering creativity, “creativity is coming up with an idea that’s not expected, or hasn't been done before, or has something unique about it. I've watched a lot of TED Talks about people doing different interesting things and I think the reason I find a lot of what people present in these TED Talks are creative is because no one's done it before.” Her vision of creativity was seeing something that was completely new and associated her this with appreciation of how she finds TED Talks engaging because of their uniqueness.
Table 24: Categories for the theme of “Essence of Engineering Creativity”

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<th>Essence of Engineering Creativity</th>
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<td>• Novel</td>
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<td>• Improvement</td>
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<td>• Multiple Correct Solutions</td>
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<td>• Multiple Perspectives</td>
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<td>• Adaptation</td>
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<td>• Application of Knowledge</td>
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<td>• Depth and Detail</td>
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<td>• Logic</td>
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<td>• Crazy Ideas</td>
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<td>• Abstract Thinking and Art</td>
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<th>Limitations</th>
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<tr>
<td>• Lack of Knowledge</td>
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<th>Discomfort</th>
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<tr>
<td>• Ambiguity</td>
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<td>• Looking Stupid</td>
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Cherise discussed how projects that were creative were the ones that had a unique quality that made them distinctive from the rest, “your project stands out from others and maybe it’s even useable in the real world or applicable or feasible or whatever because of that extra bit of creativity.”

For the majority of interview participants, being creative meant coming up with new solutions. Cassidy described her experience in her engineering design courses, “looking in those design courses we’re told that creativity is important and, you know, it's necessary to come up with new
solutions that are valuable.” Similarly, Stella felt that her instructors in her design courses defined creativity as generating original solutions, “In that sense it was more so explicitly defined that you need to be more so original with your ideas.” Charlie gave an example of engineering creativity, “with AC power and stuff, you know Tesla and Edison were always fighting over that. Like they just thought it was a bad idea and it turns out that that was one of the best and it's why we have lights right now. I think it's very important in that it’s the only way that we can make new things and come up with new ideas and stuff.” His perception of creativity was often associated to innovative ideas that had a large impact on society.

While some students limited their definition of engineering creativity to novel solutions, some students extended the concept of novelty to the approach to problem solving. Cassidy continued with her description of being creative in engineering, “It’s based on novelty and the way that things fit together and solutions, you know whether or not it's a novel way of approaching it.” In this comment, Cassidy was focusing on being creative in understanding and approaching the problem as opposed to the result from the creative effort. Stella discussed problem solving approaches with respect to new problems that each generation faces, “It’s something that someone somewhere will probably have to come up with a very different approach to the problem.”

Additionally, there were some students who associated engineering creativity with solving novel problems, that is problems or challenges that have never existed or been attempted before. Stephen stressed that creativity is important because even analytical type engineers face new problems on the job and creativity is necessary to solve these problems that no one has ever seen before, “there are opportunities for maintenance type engineers to kind of just make things work
as normal but even that requires creativity because when a new problem comes up that no one has seen before, you have to figure out how to solve it.” Scarlet had a similar understanding, “So if you're trying to be innovative then you need to be creative in the sense that you need to think of how to do something that other people haven't looked into before.” In the interviews, several students related things that have novelty with things that have never been seen before.

Another view that was voiced by some interviewees was that being creative meant doing the unobvious. Cherise discussed why creativity was an important skill, focusing on how creativity is needed to adapt to a constantly changing world. She said that, “engineering creativity involves being able to adapt quickly and to think on your toes and to not look for the obvious solution.” In her response she emphasized that creative skills are important in computer engineering which is an engineering industry where technology quickly becomes obsolete. Rueben also felt that creativity was necessary for solving difficult engineering challenges, “it will lead you to be able to solve more problems where the solutions is unobvious.”

Another interpretation of engineering creativity was that a creative solution must contain an improvement to a previously existing solution. Jack focused on the engineer who has the responsibility to improve the performance and value of current solutions, “I think if an engineer could be creative then maybe he or she will think of a better solution or like a cheaper way to do something.” Cherise commented that there is always room for improvement on engineering designs and solutions, “just because it's been done that way for like 100 years or 10 years, that doesn't mean it's the best way of doing it. I think that as engineers we always have to look for the optimal solution and that changes with time.” Jack and Cherise both made the point that
improving current systems and solutions requires an open-minded approach and the belief that things can always be improved.

Creativity was closely associated with the generation of multiple solutions. Students expressed that in order to come up with solutions that were novel and unobvious, it is necessary to generate multiple options for comparison and design iteration. Rueben commented on his experience in first year engineering that has influenced the way he thinks about what it means to be an engineer, "I guess what they always told us in first year is that engineers are problems solvers so I think the idea that there's multiple ways you can solve the problem is really important to engineering.”

Bertha recognized that in real engineering practice, all designs have multiple possible solutions, making her feel frustrated with the nature of her course work:

“I was taking a course on piping and stuff, like street pipes, and we had a project but there was only one correct solution. But when you're in the field working, say I'm laying out pipes for a subdivision, there's a million different solutions to where you can put the pipes, how big they could be. And I think that they should be teaching us more how you would do it in the field, like in the working world because I'm going into the working world and they're going to say, 'design this' and I'm going to be like, 'hmm, there's only one right answer. What's the right answer?' There's an infinite number of answers because it's all how you design and how you're creative in finding the most efficient solution.”

Bertha’s comments highlight a common limitation from all student participants which was that the majority of the work they do in engineering education has one correct method or solution.

Stella also associated engineering creativity to multiple solutions and the different ways that people can approach an open-ended problem, “I would say that really instigated creativity in that sense because when you looked at the designs, of course they had certain dimensions and similarities, but all of them were very different in the way that people interpreted it.” She
recognized that even with functional constraints, the open-ended nature of the problem results in “multiple varying responses.”

To support generating multiple solutions, many students felt that creativity in engineering meant looking at the same problem from different perspectives. Stella often referred to the ability of looking at the same problem through different lenses to truly understand the various possible solutions: “look at it through multiple different perspectives,” “look at things differently and not always follow a certain norm in thinking”, “it all relates back to perspective.” Jack shared this understanding and noted the importance of trying something different than what is expected, “I think creativity taking what you expect to be a solution to a problem and kind of putting that aside and looking at every other possibility.” Althea also commented on considering multiple perspectives when solving a problem, “[Creativity is] thinking of [a problem] from a different angle because a lot of problems you look it only from one angle. But looking at it from a different view, that helps with creativity in engineering.”

Many students discussed considering multiple perspective as “thinking outside the box.” This related to following a different path of thinking than what is expected or is considered normal. Jack stated this connection, “they do really reiterate that there we’re supposed to think outside the box, not just stay inside of what we think is normal.” Althea said that being creative is, “coming up with ideas and not just like follow the guidelines, not the guidelines but the typical answers. Think outside the box is a typical saying.” Bertha affirmed this sentiment by describing that her understanding of creativity is, “thinking outside the box and not doing what everyone expects of you.”
Some students focused on creative actions including adapting existing solutions to new applications, and applying fundamental scientific knowledge they learn in more technical courses in the engineering curriculum. Scarlet described her experience working a summer job where the company used tablet technology for a purpose that was not its primary purpose. She said adapting that technology to serve a valuable tool for the company was a creative adaptation, “I think it can be like using the exact same thing for a different purpose. I think it has to be different. For example, with an iPad, like you can use it for personal enjoyment but then a lot of businesses are starting to see how they can use it for different aspects of running their business. Like one of the companies I worked with this summer uses iPads for collecting data in the field.” Stephen explained his understanding of what engineering creativity is based on his experience in engineering design courses, “my experience in engineering has largely been looking at something that has already been done and adapting it for your needs.”

Closely related to adapting existing solutions is being resourceful. Some students felt that resourcefulness was a form of engineering creativity. Rueben discussed his improvement in being resourceful as he has progressed through his engineering education, “in school I’ve just found a way to be very resourceful overall. I’m not sure if that is specific to engineering, and I’m not sure if that’s specific to what we’ve been taught, but I found that my resourcefulness had increased a lot. I think that's pretty related to creativity.” Charlie described an instance where he was creative by being resourceful when constructing a tissue dispenser in his dorm room, “I took a roll of toilet paper from res because I was out of tissues, and I duck taped it to like the bottom of my cupboard, and now I have a dispenser. Like that was a creative implementation. I used the duct tape, I spun the duct tape to make string because I didn't have string, and I stuck that up. Now I'm able to pull the toilet paper out.” It is important to note that when students discussed being
resourceful, it was often not in the academic engineering context, rather they focused on experiences that did not reflect engineering course work.

Many students felt that they were being creative when they were applying knowledge or processes from technical courses to open-ended problems. Rueben described this expectation, “in engineering it might say we're going to give you 20 facts and then you need to be able to solve 10,000 questions using those facts, maybe that will spark more creativity.” Similarly, Stella explained what she thought it meant to be creative in engineering, “It’s trying to think of your own solution using the theoretical base that you have in the field. That’s more so what creativity is in terms of engineering. It’s using the foundational information you have and coming up with your own solution to such, maybe even evaluating, maybe even using information that is outside the course.” Stephen even discussed how open-ended projects can be used as a method of teaching the fundamental knowledge and gave an example of a design that required a control system:

“So you could say, ‘we have this problem. This is where we’re at. We don’t know how to approach this.’ And then they could say ‘well, if you look at control systems, here’s a textbook, here’s some resources, here’s another professor on staff that’s an expert in them. Learn from them how to apply that to your project. Because then it forces you to kind of quickly speed through the fundamentals and apply it to your project. And then you learn how to do it as opposed to just learning about it.’

By presenting students with design projects where students do not have the tools to approach and create a solution, they will be forced to learn the background knowledge on their own, focusing on the application of the knowledge, not the knowledge itself.

Most of the students who made the connection between having a well-established scientific knowledge for success in engineering creativity continued to discuss how being creative in
engineering education meant having depth and detail to solutions, and being able to explain logical steps and decision. Cassidy explained that she is, “assessed very broadly on the creativity and the depth of our solution.” Jack even shared an experience where he was given an assignment that required creativity. Though his solution was incorrect, he was rewarded for the depth and explanations he provided, “Actually I remember in first semester we were supposed to come up with a geological interpretation of a history of a specific rock. So like I had no idea, but I thought about what we had learned and I came up with this story that was pretty in-depth but completely wrong. My TA even said this is a great idea but this is very wrong, but like I actually got good marks for it.”

Some students associated depth with complexity, meaning a creative solution was complex. The complex nature of the solution requires an in-depth explanation for the design to make sense. Stella stated that a creative solution, “should be more complex maybe in the design.” Bertha explained that she felt she was being creative in engineering when she was, “not doing the simplest solution.”

Cassidy continued to explain that she felt being creative in engineering was related to being able to use the design process and explain the logic used throughout the process, “A lot of the feedback that I get is based on logic, especially with the process. So whether or not the steps that we’re taking or the ideas that we have are put together logically and are connected. And again there's like a huge disparity between logic and creativity. People don't think that they're the same or that they can belong in the same thing.” It was clear that many of her attitudes towards engineering creativity stem from her experience receiving feedback on her design projects. Scarlet’s interpretation was that the goal of her design reports (which required creativity) was to explain
the decision making logic so that others can understand the design process that was followed, “mostly you’re just trying to make sure that it makes sense to someone else.” Stella also said that for open-ended problems it was expected to “justify why you used what you used.”

Another common characteristic student’s associated with engineering creativity was design ideas that seemed crazy or stupid. Scarlet described her experiences when trying to be creative: “you end up getting a lot of weird ideas,” “one group had a really weird and interesting design,” and “when you think about creativity you think about crazy ideas.” Jack explained that creativity was, “looking at very unrealistic possibilities and like just brainstorming crazy ideas and then from those you could put them together for more realistic but creative solutions.”

Cherise mentioned how learning to be creative has taught her to be more accepting of ideas, even if they seem unfeasible, “I think it's kind of guided me to be more open-minded. Even if somebody else's idea first seems crazy and really out there, you're like 'well it couldn’t work, but then why not?' And I think that I've almost adapted my brain to think that way.” Cherise’s comment reflected the mindset that there are no stupid ideas. Althea articulated this feeling as well, “they say like think of your own ideas. Write them down even if they sound stupid. Like just write everything down and then discuss as a group. Like even if it's stupid, just write it down and then discuss it.” It was clear that students understood that creativity meant not only coming with crazy ideas, but also giving due consideration to those crazy ideas so that they may be adapted and iterated into a functional solution.

Though less common, some students associated engineering creativity to a classical definition of creativity focusing on abstract thought an art. Cassidy made the connection between being artistic
and engineering well before beginning her formal engineering education, “what drew me into engineering in the first place is that I do consider myself an artistic and creative person, and I’ve always been strong and science and math. But I really do enjoy that it’s both things together.” However, Cassidy continued to clarify that students often misunderstand what it means to be creative in engineering, explaining that students who can draw feel like they are creative engineers, “I know in some of the teams that I’ve been there have been students who are really good at drawing or something. They consider themselves very creative people or artistic people but that’s there’s a big difference between that and like a technologically creative person or an engineering creative person.” Althea had similar experiences working in groups on her design projects, “I hear a lot of people saying like, ‘oh, I'm not creative. I can't. Like I'm not creative. I can’t do it.’ And then they’re like, ‘oh, I'm really good at math but I can't do any art.’ It's just they don't believe they can do it.” Both Cassidy and Althea’s comments show that their peers sometimes abide by creative stereotypes. Furthermore, when discussing how creativity can be taught in engineering, Stella reverted to an artistic interpretation of engineering creativity, explaining that creative skills are developed through classical artistic expression, “a lot of time creativity is more so facilitated through more artistic activities that aren't so much just focused on your education.”

Some students related engineering creativity to abstract thinking. Stella stated this many time in her interview: “focusing on more so abstract thought and creativity,” “think on an abstract level of how you could approach the problem,” “to develop mathematics and science throughout history you need abstract thought, you need creativity,” and “it does come with very abstract thought.” She continuously associated abstract thought with being creative, though it was not clear how this differed from the thought process needed to create art. However, it was clear that
this abstract thought did not necessitate the same thought process for artistic creativity as both Stella and Charlie discussed the abstract thought required to understand linear algebra. Charlie commented, “in our linear algebra thing today we learned about eigenvectors and values and stuff like that. I don’t know what it means. It’s just like some very abstract concept that means absolutely nothing.” Similarly, Althea said, “I guess with linear algebra because they’re trying to [think creatively]. Like that’s such an abstract subject so you have to be creative. Abstractly think of how it connects.” Both students noted how abstract thought in math subjects is difficult and how this can impact attitudes towards creativity.

4.3.2.1 Limitations

As students were describing how they interpreted engineering creativity, their responses led to them to realizations of the limitations that arise based on their definitions. The first limitation that was identified in the analysis was the lack of knowledge students possess of design and engineering creativity. Some students expressed a lack of confidence in design skills because they felt unprepared and lacking design process knowledge. Bertha, who was about to graduate from civil engineering, expressed her lack of confidence in being able to work in the field due to her lack of knowledge and limited preparation, “like I don’t feel ready. I feel that whatever job I’m going to go into next year is going to have to teach me everything I need to do because right now I feel like I can do math and physics. I don’t feel like I’m ready to design a bridge or build a building.” Charlie commented that his peers have difficulty with creative because of their approach, “a lot of people have a tough time being creative and a lot of people go about it the wrong way I guess.” Jed had a difficult time articulating what he thought engineering creativity meant, “I don’t really have a definition of engineering creativity, I would have to think about it.” Stephen also noted that he didn’t feel he learned how to be truly creative in engineering until his
third year design course, stating that in first year engineering, “it’s just sort of implied that we know how to be creative.” He continued to express his frustration with the expectation of being creative while not having a clear understanding of what it means until the latter parts of his engineering education.

Another limitation is the common misconceptions students have when it comes to engineering creativity. Many of these misconceptions were rooted in stereotypes of engineering and about creativity. Althea noted that she didn’t initially feel creativity was a part of engineering and said the connection needs to be more explicit in her courses, “I think it should be more blatantly obvious in the courses when they talk about [creativity] because a lot of engineers go in and don’t think about creativity. They think math and jobs.” Scarlet commented how it was more difficult for her to see the application of creativity in her discipline of chemical engineering as opposed to disciplines where the connection may be more obvious such as mechanical and electrical engineering, “so I find it hard to figure out how to connect creativity to a chemical engineering process because I feel like it's sort of just been done before.” This misunderstanding, that creativity can only be applied to product design, limits students who are in disciplines where creative thinking is more noticeable.

The perception that creative ideas are complex was another misconception that emerged through the analysis. Scarlet described her experience with creative ideation in some of her design projects and how they ultimately reverted to a simpler design because of complexity, “so it's too complicated. We don't really know how it works. It's weird. It's never been done before. We didn't choose it because it's not really well known.” Charlie gave an example where he was being creative in his robot design project and noted that his idea was creative because it was more
complex than the typical designs, “in my project there's tons of roadblocks and stuff. We're realizing it was too advanced and that's most of the reason people do mazes, for example. Because it’s very simple. So there's definite roadblocks. A lot of the time stuff is too advanced.” It is clear that there were instances when the complexity and depth required for a creative solution deterred students from being creative.

Additionally, students identified limitations with the creative stereotypes of crazy ideas and the connection between creativity and art. Scarlet articulated the limitation to creativity she experiences from her experience proposing crazy ideas in her group projects:

“That actually happened to me my group. I came up with some weird ideas but my team members threw them out right away, which is fine but it sort of makes you less inclined to come up with these crazy wacky ideas because you don't want to feel like you’ve wasted your time. If you know it's not going to work anyway and you have this preconceived notion that it's not going to work from the start, you kind of just go with like a bit more of what's typical or expected.”

Charlie described a similar instance when he was proposing crazy ideas, “a lot of the times you propose a wacky idea and then everyone just immediately looks at you. And I think that's what makes people feel think I'm not going to do that again.” When Scarlet and Charlie wanted to be creative in their projects, they focused on proposing creative ideas. This attitude limited their creative idea generation because they did not recognize the potential for creativity from ideas that were more practical in nature.

Cassidy commented on how students often get stuck with the association of creativity and art. She said that there is a difference between creativity in the arts and creativity in the engineering that a lot of students do not recognize, “I know in some of the teams that I've been there have been students who are really good at drawing or something. They consider themselves very creative people or artistic people but that's there's a big difference between that and like a technologically
creative person or an engineering creative person.” She continued to explain how this attitude also discourages students from attempting to be creative because they feel they are not creative.

Cherise focused more on the limitation of inexperience with solving open-ended problems, “the problem with it is that people don't usually understand it enough to be able to take that open-ended problem and go, 'OK. Here's the direction I want to go with it.'” The limitation of inexperience was often connected to the lack of fundamental knowledge. Althea felt that idea generation itself was not challenging, rather it was the technical functionality that limited the implementation of creative ideas, “I know other people that that's all they can do, is come up with ideas and they don't think of the technical side or anything else, just the ideas.”

Some students described a self-identified limitation where they had difficulty with ideation after thinking of their first idea or being exposed to examples of solutions. These comments highlighted the problem of fixation which is a challenging barrier that students can experience when attempting creativity in engineering. Stella described her experience with a robot design project:

“The example given on the sheet was a maze. I'm going to create a maze in which the robot bumps into an object and reacts to such and moves. A large percentage of the class then very much focused on mazes or obstacles, object oriented programming, rather than thinking of a more original solution. So when you're kind of stuck in that mindset for a while it can be very hard to generate creative ideas.”

Her comments illustrate the difficulty students have with trying something new and different after being exposed to an example of an acceptable project.

Charlie reflected on a project he did where he was fixated on an initial solution, but through encouragement from his TA, they were able to consider alternative solutions and had a more
creative result, “we were a little bit too stuck in our ways. Like we had an idea of what we wanted to go with but I was just at the proposal stage. So then after that our TA basically said you guys need to back off a little bit, open up your minds, think about more ideas. That actually really helped in our final design.” Similarly, Jack described his fixation as inherent in his personality, “I feel that my personality, I am more susceptible to getting into the groove and staying there and not being willing to move out.” Some students attributed their problems with fixation to their temperament while others attributed it to the way they’ve been taught to think and solve problems.

4.3.2.2 Discomforts

Students discussed discomforts associated with their definition of engineering creativity that could potentially have a large impact in their engagement in the creative process. Some students explained that they were uncomfortable with creativity because creativity occurs when there are multiple correct solutions to a problem. The ambiguity in results was discomforting to several students. Scarlet described this feeling with respect to the ambiguous nature of problems that require creativity, “I think [not having a right answer] is nice but it can kind of be uncomfortable too. I think that's what actually makes a lot of students uncomfortable because they're like, ‘I don’t know if I’m doing it right because there isn’t a right answer.’” She continued to discuss her motivation for studying engineering:

“The reason that I like STEM, this stream, is because there usually is a right answer. So I think that when I was in high school, like I hated English. I hated anything that had essays or something where you couldn't get a final numerical answer and be marked right. Like I'm very much a black or white person. So I think when you take a bunch of people who think like that and you put them in a design course where there isn't a right answer, it makes them very uncomfortable because it's not what they're used to.”
Stephen had a similar opinion, “I felt like I was kind of really struggling with the idea of coming up with multiple solutions and struggling with the idea of approaching problems from different angles. Just generally struggling with being creative in a science based field where I've been told that there's always the right answer.” Scarlet and Stephen’s comments highlighted the problem with the attitude students can develop in high school where their teachers reward students for following a single correct procedure and producing the correct results. As math and science courses are prerequisites for engineering, many students who come into engineering tend to have this mindset and it can impact their creativity.

The second discomfort expressed by students was with proposing ideas that were wild or crazy. The fear of looking or sounding stupid to peers was mentioned by several students, ultimately discouraging them from proposing ideas that may not seem feasible but can potentially stimulate other creative ideas. Stella described her thoughts when proposing ideas to her design team, “again that fear is there, that stipulation. What if this isn’t a very good idea? What if no one likes my idea?” Scarlet felt similarly, “a lot of people I think are sort of cautious or apprehensive about sharing their ideas because they don't want to look stupid or get turned down.” Althea also shared this experience in her design course, “I know they say don't worry about coming up with stupid ideas but it's always hard because you don't want to be like, 'oh, what about this' and people are like ‘seriously?’” Some students show a hesitance to share ideas which can result in a lost opportunity for pursuing a creative idea and discourage students from suggesting ideas in the future.

4.3.3 Creativity Expectations
Throughout the interviews it was common for students to differentiate between their personal attitudes towards creativity and their perceived expectations from their instructors with
engineering creativity. As a result of these perceived expectations, most students expressed value for creativity in engineering, however this usually did not translate to academic value for engineering creativity. The categories in this theme are outlined in Table 25 and encapsulate the different expectations, some of which stem from instructors’ expectations and others from personal expectations. Many insightful limitations and discomforts were identified which were attributed to the nature of a demanding engineering curriculum.

Table 25: Categories for the theme of “Creativity Expectations”

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<td>• Correctness</td>
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<th>Limitations</th>
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<th>Discomforts</th>
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<td>• Interpretation of Creativity</td>
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Many of the students who were interviewed agreed that their instructors expected correct solutions more than sound process or approach. Even in design, the emphasis was on the accuracy of the technical aspects of the design more than the overall design process. Cassidy commented on her design projects, “it does become much more focused on the technical and feasibility, and risk and safety side versus creativity and innovation.” She went on to point out that expectations...
are driven by assessment methods which are heavily focused on the correct answer, “I think there's a huge push towards the right answer over process. Like you need the right answer to get the marks, so that's where people go instead of exploring different pathways.” Scarlet also felt that creativity suffered because of the expectation of being correct, “it’s usually about well is it going to work? So I find we will often go with things that are less creative and things that have been done before or are more familiar because you know it's going to work in the end and that's mostly what is assessed.” Limitations from assessment and getting the right answer was consistently mentioned in all the interviews and was one of the primary topics of discussion detailed in Section 4.3.3.1.

Other students felt that their design course instructors displayed more value to the problem solving process, but creative expectations remained lacking. Stephen explained, “there's a lot of emphasis on not so much the actual solutions or creativity you display, it's a lot of did you use the tools properly and did you format your report right.” Similarly, Stephen made the connection between assessment and being creative, “there's a pressure to get to the end of the project and that's very counter to being creative because you're expected to get to a certain point to earn your marks.”

Stemming from the focus on accuracy and correctness of solutions, students expressed that they felt pressure to take the standard approach when given the opportunity to be creative in design. Rueben described his perception of the expectation of creativity, “I would say generally we’re rewarded for doing stuff that's more standard and for having stuff that just kind of meets all the expectations that they have.” Charlie gave an example of how his instructor was surprised that his group was not doing the standard design, “probably 80% of the people did [a maze] and that's
almost what they expected. It's like a TA would come up to me and say 'what's going on in your coding?' They'd be almost confused that I'm not doing a maze type thing.” Many students pointed out that it was possible to be successful in engineering education by taking following the standard path without being creative, influencing their attitudes toward creativity expectations.

Cherise described her experiences with open-ended problems and how her mentality was to put her initial effort into understanding exactly what the standard expectations were, rather than using the design process to break down the problem, “I think the first thing I think of when they give me an open-ended project is like well what do they want? What do they want to see when you’re done?” Scarlet had a similar experience, elaborating on how as a fourth year student she felt less creative than when she started her engineering education, “I used to think I was more creative than I do now which is interesting especially being like a fourth year engineering student you’d think that I would be more creative now. But I think like you kind of get used to doing the expected when you’re going through your courses.” Her comments show how creativity can be driven out of students and how attitudes towards creativity can change over time due to influences from the creativity environment.

In addition to students’ perceived expectations from instructors they also expressed a common sentiment that being creative required extra effort. Many students articulated that because creativity meant doing something different from the standard expectations, going beyond these expectations required extra effort. Rueben said, “the people who are creative in engineering and in the work that they're doing are people that are saying 'well maybe I can get this done in an hour but maybe I'll spend an hour and 15 minutes and just try one or two new things.’” He associated this extra effort to considering multiple solutions to the same problem.
One of the consequences of the extra effort required for creativity that the students identified was that this meant being creative demanded more time. Cassidy stated, “if I had time to really delve into this and look at it carefully then I would but I don't have the time to do it so it's whatever I can get done in the next two hours and then I have to be done.” This mentality highlighted the impact of the heavy workload that comes with undergraduate engineering to promoting creativity in projects and assignments.

Cherise gave an example of an experience when she put in the extra effort to produce a creative design but was not rewarded for her efforts:

“in first year we had our graphics project where you had to make a 3D model and we had a camera or a clock or something else. And I did the camera and I was like I'm going to model my camera. And I spent forever modelling it because I was really into it and I got really creative and everything. I spent probably like three times as long as anybody else on my project and I got the exact same mark as everybody else right. So that was kind of one of those times where you didn't need to be so creative, you could've just done a simpler approach and gotten the same outcome.”

She went on to explain how her motivation to be creative in future projects was negatively impacted and she now focuses on understanding what the instructor’s expectations are in order to maximize her grades. From the tone of many of the interviews, it seemed that students truly wanted to put in the extra effort in projects that require creativity, but the pressure of obtaining high grades greatly influences their study habits and attitudes towards learning content that is not necessarily rewarded with grades.

4.3.3.1 Limitations

The limitations under the theme of Creativity Expectations were the most prominent throughout all the interviews. Students regularly discussed how being creative was challenging because of
the extra time required to take a creative approach, a symptom of their intense workload. They also expressed a lack of motivation to be creative because it was rarely rewarded and the feedback they generally received was not useful for enhancing the creativity in their projects.

Some students felt that they did not have the time to be creative because of the workload in undergraduate engineering. Because there are so many tests and deliverables, students said they have been more focused on completing the assignments to an acceptable standard rather than spending extra time to be creative. Scarlet expressed the viewpoint, “I feel that a lot of the times we don't have a lot of time to do these assignments because there's always so many for different courses. So you kind of just do something that you know will be good, like it's technically sound but it's not the most creative idea you could've come up with because you just don't have the time to keep working on it.” Jed felt the same way, “there's so much [work] in engineering a lot of the time you're just focusing on checking things off the to do list and instead of taking the time to do a project well.”

Charlie felt that the problem of time needed for creativity was caused by the time required to come with a truly creative idea, rather than the limited time caused by a heavy workload. He explained, “you know with a lot of these projects you have like two weeks kind of thing and that's it. And if you wanted a genuinely creative idea to this approach, maybe I need a year to find it in nature, to find something inspirational on the street and I think how can I apply it to that.” He understood that creativity requires time for idea incubation, but felt the length of semester does not provide sufficient time.
An interesting finding that emerged from the analysis was that students have a keen sense of value for effort. Almost every student who was interviewed commented on how the intensity of an engineering program required them to determine where to put their efforts in order to maximize their grades. Cassidy explained her strategy, “if I can put two hours in and get really good marks then that's what I'll do rather than put four hours in and get maybe not so good marks.” Bertha had a similar response, “I think it's more effort base to be honest. Like if I was going to get more marks for being creative but it would take seven hours longer than it would to just do the way that everyone else is doing, I don't see that reward.” Cherise also commented on the value of time and effort, “I think it's almost like there’s a time and place and you have to pick and choose where to put the extra effort and extra time.” It was clear that this subjective calculation was driven by the lack of assessment of engineering creativity.

Assessment of creativity was another limitation with respect to creativity expectations. Students explained how creativity was rarely evaluated in their design projects which influenced their interpretation that creativity is generally not expected in their course work. Stella focused on how instructors define expectations through rubric criteria, “I don’t believe it’s something that’s very much valued. I mean for example, for a lot of projects TAs, from what I understand, are given a certain kind of rubric to follow in terms of marking... Anything that’s not within that given criteria is irrelevant to their realm of marking or even evaluating the project.” Jed responded to how creativity is assessed and mentioned that complexity of ideas was evaluated rather than creativity, “I think the majority of it is going to be how complex it is but if you have a creative idea I assume that they don't notice that but I wouldn't say they assess creativity very much.” Jack confirmed that a creativity element does not appear on his projects, “like generally there's not like some specific criteria for just creativity.”
Bertha was the only interviewee who mentioned that she recalled seeing a creativity section on a project rubric, however it was not clear how this criterion was actually evaluated. She commented that the evaluation was focused on the result and not the creative process, “for my fourth your design project, one of the things on the rubric was creativity and innovation. And it was not assessed well... It would just seem like it was a very closed door, like yes you were creative or no you weren't.” Cassidy also mentioned how, even in projects where creativity was promoted, it was unclear how creativity was being evaluated, “I don't really know how we’re being marked on [creativity] or a lot of the students don't really know.” These limitations with assessment highlight how students principally value skills that they are evaluated on. This problem is compounded by the difficulty of evaluating the creativity construct for engineering projects.

Another limitation within this theme was the focus on the feedback students receive on their deliverables. Throughout the interviews it was evident that students understood instructors’ expectations through what was being assessed and the type of feedback they received. This was problematic for applying creativity because students felt that it was not assessed and their feedback is focused more on communication and technical specifications. Scarlet discussed her feedback on her design reports, “it's mostly commenting on formatting but then also like is your design going to work or this is wrong, less so on the innovation aspect of it I think.” Cherise’s experience with feedback on design reports was limited to single word comments that were not useful, “most of the time at the end is kind of like ‘neat’ and you're like ‘alright.’ Like I don't think we usually get very much feedback on creativity so much as it's like, did you do the project and did you do it well?” Jed had the same problem, “I wouldn’t say the creative aspects were touched on in feedback. More so just the minimal, ‘good idea’, ‘good approach’, that kind of thing.” Scarlet continued to note that even if an effort was made to be creative, there is still little
feedback, “I don’t really see where it’s assessed or like I don’t think we get specific feedback on how creative our design is or if we’ve taken that effort to come up with something completely different than everybody else.” In consideration of these comments, it was apparent that there was a disconnect between the assessment feedback loop and creativity.

4.3.3.2 Discomforts

The discomfort that students expressed in the theme of creativity expectations was grounded in the ambiguous and subjective nature of creativity. Some interview participants commented on how they did not feel confident applying engineering creativity because they were afraid of the way it would be interpreted. Stella described this notion, “what if the TA marking me doesn’t personally like that? [Variation in marking] is also something to worry about in terms of being creative. I mean not every marker is going to be the exact same. Everyone is going to interpret it very differently, so that's kind of where there's a little bit of bias and a little bit of a stipulation.” She continued to explain her discomfort, “you are very much afraid of being a little bit creative in the way that you present information because you do fear in the way it's going to be interpreted.”

Cherise also commented on her discomfort with the arbitrary way that creativity can be assessed, “if you give everybody complete freedom with the project. how do you mark them? You have to have some type of standardized part otherwise like it's really arbitrary and then somebody's arguing their mark.” With a similar tone, Stephen remarked on how it would be difficult to develop a reliable measurement of project creativity, “I don't know if the solution is necessarily to change so creativity is marked because then you get into issues of how do you even begin to do that.” Cassidy pointed out that giving marks for creativity is problematic because everyone
interprets creativity differently, “it seems like very arbitrary to be marked on the creativity of your solutions when like what is that creativity? Everybody has a different idea of what a creative solution is.” Her response showed insight into the challenges that arise with measuring latent constructs, that is how do you assess something without having a clear and universally accepted definition.

4.3.4 Motivation for Creativity

The fourth theme encompassed what motivates students to be creative in their engineering coursework. The primary motivations were extrinsic in nature, focusing on rewards for creativity in the form of grades. However, there were four intrinsic motivating factors identified through qualitative analysis that concentrated on the educational benefits to being creative, and how being creative can be gratifying. The categories are described in Table 26.

Table 26: Categories for the theme of “Motivation for Creativity”

<table>
<thead>
<tr>
<th>Motivation for Creativity</th>
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<tbody>
<tr>
<td>• Reward with Marks</td>
</tr>
<tr>
<td>• Useful Skill</td>
</tr>
<tr>
<td>• Enhances Learning</td>
</tr>
<tr>
<td>• Genuine Interest and Passion</td>
</tr>
<tr>
<td>• Creativity is Fun</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Not Rewarded</td>
</tr>
<tr>
<td>• Teachable Skill</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Discomforts</th>
</tr>
</thead>
<tbody>
<tr>
<td>• N/A</td>
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The limitations for the motivation theme focused on the extrinsic factor of assessment. As well, an intriguing limitation emerged from how students have opposing views on whether or not creativity is a teachable skill.

One of the most common topics discussed in the interviews was assessment in engineering education. It was clear from the remarks of all students that assessment of creativity was necessary to encourage students to be creative. Bertha stated, “I mean if you make it for marks everyone will have to do it.” Students stressed how they would not do any work unless it contributed to their final grades. Stephen recalled instances in his engineering education career where he neglected assigned work because it was not being graded:

“there's a lot of different courses. Every course has assignments and every course has readings, and I personally haven't done any readings ever in the last four years because they’re not graded. You don't get marks for them. And then the same thing with assignments. If I didn't get marks for them then I didn’t do them until two or three days before the exam to study because the exam is where the marks are. So to encourage creativity, the most obvious answer is to reward points for it or marks for it but again that runs into the issue of how do you do that.”

His comments highlighted two notable considerations: (a) marks are the most important concern for students and (b) it is difficult to reliably measure and assess creativity in engineering projects.

Some students felt that in some cases, mostly in design courses, being creative could have a positive effect on grades. Jack described this as going beyond expectations, “basically there's meeting expectations and then there's extensions which is moving beyond that and I think often that's where creativity comes in. I think when you propose a creative idea maybe even if it's not the best report or you don’t have the best formatting or whatever, I think that’s reflected in grades.” Cherise had a similar experience and gave an example of how one of her assignments allowed her to go beyond expectations for bonus grades:
“I had a graphics assignment a couple of weeks ago closer to the beginning of the semester and we had to create the Asteroids game where you have the little spaceship and you have to shoot asteroids. And so basically you just had to have the basic functionality working to get the marks for the project but then your group could add in random things. So we added little spaceships in the corner to track your lives, and a score meter at the top, and levels so every time you destroyed all the ones in your level more asteroids would come in next time. So I guess they encouraged [creativity] that way and it’s usually through like extra marks.”

From these responses it was clear that rewarding creativity was the most important factor when motivating students to put in the extra effort required for creativity.

In addition to motivation through grades, some students recognized the importance of developing their creativity skills to improve their capability of solving new and complex problems faced by society. As well, creativity was credited as an employable skill that can make a new graduate stand out from their competition. Rueben felt that teaching students to be creative produced more versatile graduates, rather than students who were skilled technically within an academic environment, “if you focus more on the creative side of things then you’re going to have more well-rounded people.” He also argued that creative engineers are much more valuable to the engineering industry, “if you just know how to solve one problem, sure you’ll be good at solving that one problem and there will be people who need to continuously solve one problem but you’re going to become much more valuable if you can have the creative skills to solve multiple problems.”

Bertha felt that creative skills are essential for good engineers, “I absolutely think that you’ll meet the best engineer and he’ll have done the most obscure projects and tried different designs. I think that being creative is part of what makes you a good engineer.” Scarlet also found value in creativity as a useful design skill, “I think it is important to have [creativity] in any aspect of your engineering degree because otherwise you get bored with what you’re learning and you don’t feel
like you're working towards something that's really going to help you design in the future.” Her response also showed how creativity can be engaging and provide a different experience than the typical math heavy curriculum.

In addition to being a useful and employable skill, some students felt that creativity enhanced the learning experience. Projects that required a creative element encouraged deeper learning and understanding of engineering concepts. Rueben discussed his experience when creativity was an important element of his engineering projects, “I was able to learn a lot more even on the technical side when there was a creative aspect because you just felt like you could apply the things that you were learning to stuff that was more fun, opposed to when it's very rote and very by the books.” Stephen expressed the same feeling, focusing on how skills taught in class are quickly forgotten if they are only required for answering exam questions. He stated that the skills that he has continued to possess are things he learned while doing open-ended projects:

“as much as I can get an A+ in the course, if I don't use that material I lose it. And I can think of so many courses that I've taken over the four years that I did really well in but I'm sure if I took an exam tomorrow, I would not do anywhere near where it was... So it seems to me that it would be better if they switched to more project-based things that encouraged learning of different subjects and then having professors to guide.”

Some students also felt that creativity contributed to a deep understanding of course content. Rueben said, “with the engineering courses I'm taking I've been a little disappointed that there's really no creativity and when there's no creativity I find that there's no deep understanding.” Charlie’s response was similar, expressing that creativity is required for application of course content to situations not explicitly taught in class, “I think that really proves you understand the topic because you have to go into your own mind, take an idea that you made, a completely unrelated idea, and apply that concept back into it. And I think that's the kind of importance of the creative part.” Cherise commented on how creativity really motivates her to take a deeper
approach to learning, “I guess would say like creativity kind of pushes you almost to trying new things and try harder at other things.”

Genuine and interest and passion for projects was another motivational factor identified by the students. Some students focused on how motivation comes from passion for the project and encourages engagement in the design process while other emphasized that interest in projects arises when students find the projects personally relevant. Charlie focused on how there needs to be self-interest in order to prevent students from doing the standard. He emphasized the instructor’s responsibility in providing relevant and interesting projects to motivate students to put in the extra effort required for creativity, “So I don’t really know how much they encourage the creativity. It's more up to whoever wants to take it to heart or just kind of throw it out and do the generic thing.” Similarly, Scarlet mentioned that, “creative people are very self-motivated.” Jack felt that motivation was more related to ambition which is a unique case of self-motivation, “I think creative people generally have big dreams and big visions. They really want to go above and beyond what's expected of them.”

Interest in projects also tends to go hand in hand with involvement in the project. Jed recognized that interest in the project impacts an individual’s involvement. He explained that truly creative people are immersed in their projects and genuinely care about the results, “they’re not just there to get the project done, they care about it.” He even provided an example of a where he was not creative because he lacked passion for the project, “there’s so much [work] in engineering that a lot of the time you're just focusing on checking things off the to do list and instead of taking the time to do a project well. For example, the graphics course I could spend the extra three hours
and make my MP3 really cool but I don't really care about graphics.” His response showed that his perception was largely influenced by the workload in engineering.

The final motivational factor that students discussed was how being creative in engineering was fun and enjoyable. Students identified that when they were having fun with their projects, they become less concerned about maximizing grades and voluntarily put in the extra effort required for creativity. It does not seem like something that they have to do; it becomes something that want to do.

4.3.4.1 Limitations

The first limitation in this theme was the lack of reward for creative effort and output. Several students articulated how creativity was not a priority because it was not assessed in any meaningful way. Scarlet stated, “I don't think that creativity is really that important to the students in that sense because they don't think that's what they're getting marked on.” Stephen commented on his heavy workload in engineering and how creativity was often overlooked because marks were generally not rewarded, “[creativity] is the least important thing because is not reflected in grades.” He continued to explain that his main concern with putting in the effort to be creative was whether he will receive a better mark than someone who did the standard solution, “after doing all that work, will I be rewarded for [creativity]? Not even so much will I not face mark penalties, but will I get more marks than the guy who just did the rote standard answer.” Stephen’s response highlights an important contrast in opinions where some students felt that creativity was simply not rewarded while others believed that being creative had negative impacts on marks.
Charlie’s experience in his first year design course illustrates how he developed the perception that creativity can have a negative impact on grades, “I knew many people who did a maze and got 100%. Whereas people who took the creative, fun, new idea, and it might have some kinks in it because it was harder, usually end up getting worse marks.” Charlie continued to make some concerning comments on how evaluation practices not only ignore creativity, they also can deter students from being creative strictly because of their focus on getting high marks. Charlie discussed his experience in a group design project where his teammates were focused on marks and not creativity, “most of the time people are used to being non-creative and kind of like ‘let's just get the good mark.’ And most the time, for me at least, groups are kind of detrimental to the creativity of it.” Stella made a point that even very studious and high achieving students do not attempt creative solutions because of the potential negative impact on their grades, “if you're very committed student in terms of your grades, you might be more focused on the negative output that can come from it.” This comment was concerning because it suggested that students may avoid taking the risk of being creative and developing their creativity skills because of the potential negative impact of trying something different.

The second limitation was related to the attitude students have towards teaching and learning. When students were asked if creativity is a teachable and learnable skill, there were mixed responses. Some felt that creativity was a skill that was no different from other professional skills that can be enhanced through education while others argued that creativity was a natural skill that only certain people possess. The students that thought of creativity as a teachable skill believed that with good instruction, ample opportunity, and enough practice, anything can be learned. Cassidy related her experience learning to sing to learning to be creative. She explained how she was able to learn how to sing without having a natural singing ability, “I sing as well and if
anyone can learn to sing then anyone can learn to think creatively and there's some people who really can't sing out there and they're fine. I think it's just something that you need to practice like anything else. Expose yourself to situations where you're forced to think creatively or forced to think about things in a certain way or in a way that's not comfortable I think is such a huge thing.” In her response, Cassidy pointed out the importance of practice when it comes to developing skills like creativity. Stephen had a similar response:

“I don't think there's anything different from learning how to be creative as opposed to learning how to do math as opposed to learning how to sculpt. I think if you really want to do it, you can focus in enough to learn how to do it. Creativity is a skill. It's something that is learned. Just like any other skill, some people are born more inclined towards it with a better aptitude towards it but in the end of the day I think that if you take the time to try to learn it, you definitely can.”

He maintained that some people may be more creatively inclined than others, but that does not mean that engineering students cannot learn to be creative. Althea expressed the same feeling, “I mean anything you want to learn, you can learn. That's my belief in life. It might not come as easily but you can learn it.”

Some students, such as Scarlet and Rueben, felt that people are born with a certain creative skill level that can be fostered and improved with proper instruction and guidance. Scarlet mentioned that she believes everyone is creative and that once you are taught good creative process, creativity can be enriched, “I think that everyone is creative. I think it's about showing people sort of how to use your brain and how to bring out your creativity and I think you can do that.” Rueben said that, “I guess there's a baseline of creativity for a lot of people. So maybe you're not going to be able to take the least creative person in the world and make them into the most creative person but you can maximize an individual's creativity that they have inside of them. And it just depends on the way that you want to set up your courses.” These students were not limited in learning to be creative because of their attitudes towards learning new skills.
However, other students felt that creativity was a natural skill and that trying to teach people to be creative was not possible. Jed stated, “I’d say you could give students opportunities to develop their own creative skills or give them material but I don't think it can be taught in the classroom.” Bertha had a similar sentiment, expressing that creativity cannot be taught, rather it can only be stimulated “I think it can be encouraged. I don't think you can teach someone to be creative.”

Cherise expressed that she felt creative ability had a lot to do with the environment you grow up in and that creativity is a skill that is developed overtime and through experience, not through traditional course lectures, “it's kind of like one of those soft skills that people are just going to pick up as they grow up and I think being in a more like creative household can make you more like that than other people.” Stella felt that creativity was not something that can be taught through a traditional course:

“I mean creativity, the way I think of it, it's not it's not something like a course. It's taught in many ways that we don't even expect. It's not something in which we all sit down and someone’s sitting in front of the blackboard and says 'OK, this is how to be creative.’ It's more so something that's facilitated through hobbies and things that you do outside of academics... It's something that is very much evident in maybe even your upgrade bringing. In the different activities that you've involved yourself with in childhood and in different activities you get involved with in your university studies.”

The perceptions of these students has limited their motivation to learn to be creative because creativity was viewed as an inherent trait more than a skill that can be learned in engineering education.

4.3.5 Requirements for Creative Success

The final theme that emerged from the qualitative analysis captured different elements that students felt were required to be successful when being creative. The responses focused on the mindset of students when they are working on projects that require creativity, as well as the environment that is essential for a successful creative effort. The categories for the theme are
listed in Table 27. The major limitations students noted were the lack of authentic effort with creativity in design projects, and the major discomforts were related to students’ predetermined inabilities to be creative, and challenges that arise from group work.

Table 27: Categories for the theme of “Requirements for Creative Success”

<table>
<thead>
<tr>
<th>Requirements for Creative Success</th>
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<tbody>
<tr>
<td>• Open Mind</td>
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<tr>
<td>• Group Work</td>
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<tr>
<td>• Working Environment</td>
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<table>
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<tr>
<th>Limitations</th>
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<tbody>
<tr>
<td>• Lack of Authentic Effort</td>
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<table>
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<tr>
<th>Discomfort</th>
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<tbody>
<tr>
<td>• Predetermined Inability</td>
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<tr>
<td>• Group Work</td>
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Most students identified having an open mind as an essential characteristic for creative ability. The capacity to approach problems without predetermined solutions was heavily emphasized, as well as the consideration of multiple procedures. Stephen discussed being open minded by taking a holistic view of the whole problem and not taking the problem statement at face value. He said this requires a degree of open-mindedness to detect where the problem can be influenced:

“I think engineering creativity comes down to being a very open-minded and very kind of holistic when approaching a problem. And that's something that definitely came up a lot. The idea that your client or whoever your project manager is, whoever comes to you with a problem and they say what the problem is, what you have to do as an engineer is take six steps back and take a look at the holistic system. And then creativity comes in looking at it and saying where can I influence this problem? From where does this problem originate from? Is there even a problem? What do I need to actually fix?”
Stephen’s recognition of open-mindedness as a key element for creative success aligned with his definition of engineering creativity which focused on engineering design, problem solving, and looking at problems through multiple perspectives.

Cherise focused on being open-minded to other ideas and solutions, especially the ones that did not seem particularly feasible when first proposed, “I think it's kind of guided me to be more open-minded. Even if somebody else's idea first seems crazy and really out there and you're like, ‘well it couldn’t work, but then why not?’” She continued to say that being closed to new ideas and ways of thinking is not only detrimental to creativity, it is detrimental to learning in general, “I think if you're closed off and not open to new ideas or new ways of thinking or new anything, it'd be very hard to learn anything let alone how to think differently and kind of adapt your ideas and take other people’s ideas and combined them.” Similarly, Jed emphasized that being open minded is essential in order to avoid eliminating ideas early on in the design process, “[creativity] requires open mind perspective on the solutions. So you don't want to rule anything out right away. You want to be able to take ideas from anyone and you don't just necessarily want to do the expected approach.” His comments elude to his perception of the mindset needed to be successful with creativity in a design project. His extension of open-mindedness to not doing the expected illustrated how he interpreted engineering creativity to be trying new methods and procedures.

The second category under the theme of Requirements for Creative Success was related to group work. There was a strong association between group work and being creative which was mentioned by every interview participant. Most of the experiences with engineering creativity that students discussed were in the context of group projects. Cassidy stated, “the context where
we are encouraged to be creative is all in a team context.” Althea also explained how her understanding of creativity was in the context of group projects, “a lot of them say like when you're trying to work creatively, because I'm thinking mostly in terms of group work, they say like think of your own ideas, write them down even if they sound stupid, and then discuss as a group. It seems to be every single [professor] that talks about it says that exact same thing.”

The majority of students commented on how working in a group helped with being creative because there were other students to give input on ideas, making it easier to explore multiple perspectives. Cherise described her personal experience with group work and creativity, “usually for me I get more creative sometimes with group work because if I bounce these ideas off other people, I can see what they think of them. And I work really well when I can talk out ideas with people.” Stella described the same sentiment, “sometimes a lot of creative ideas come from bouncing ideas off of another person and building on ideas and another person's ideas.” Stephen was adamant that group work was necessary for engineering creativity, “you can feed off each other's ideas... Group work is essential to be creative in an engineering sense.” The connection between group work and creativity was aligned with the association between creativity and design, as most of the students’ design projects are completed as a team, not individually.

Jed even mentioned how group projects encourage creativity because students are forced to share their ideas and work together to develop those ideas into a solution that satisfies the whole group, “I think [group work] encourages [creativity] as opposed to individual work because you're bouncing ideas off of people and you're getting just more input into the project or whatever you're doing... But I say just having more input and having more like different perspectives helps with the creative process.” Jack focused more on how working in a group made him feel
accountable for bringing a creative mindset by considering many possible solutions rather than
going with his first idea, “I guess one aspect is accountability in a way. Like if I’m by myself I
generally wouldn’t come up with creative ideas. I’d just come up with one idea and run with it.”
Charlie explained how having other group members who are passionate about the project can help support the creative effort, “if you have another creative person then it's like ridiculous how helpful it is. Just crazy ideas coming up everywhere and you accept everything.” In his response, Charlie also pointed that students who are passionate and creative tend to be more open to considering different ideas, no matter how ridiculous they might seem. From these responses it was clear that students considered a well performing and cohesive group to be essential for a successful creative effort.

The third requirement that students perceived as contributing to a successful attempt at creativity was a positive working environment. Students had different perceptions as to the characteristics of an environment that was conducive to creativity, though the overall sense was that students needed to feel relaxed and comfortable. Jed stated, “I think a calm and friendly environment is good for creativity because you're not stressed out about completing something. You can kind of just hang out if you want and that's a good time for good ideas to come around.” Stephen had a similar feeling, “you want to be as relaxed as possible while still feeling like a very productive environment. Somewhere that work gets done.” Jack said that his ideal environment for creativity required an active atmosphere and added, “I think the environment is good because it's relaxed. Like we don't feel uptight. I think when I feel relaxed I think my mind is more open, when I don't feel like there's a rush.” These comments indicated that students found the divergent thinking component of creativity difficult when they are stressed.
Some interview participants felt they were most creative in an active setting. Small distractions were welcome in this environment as they were noted as providing inspiration for creative ideas. Scarlet said, “I know in my group we actually went to Queen’s Pub for our idea generation because you kind of get people moving around you. There’s stuff going on. There’s stuff on your table. You’re looking around the place and your mind’s not staring at a wall forcing yourself to come up with ideas.” She explained that this atmosphere allowed her to get inspiration from different things that were going on and helped spark ideas that would not emerge in a more isolated environment. Charlie had a similar experience where he was able to successfully design a cruise control function for a robot when the idea had been incubating in his mind for some time, but realized the solution while being distracted with other activities:

“I'll kind of turn my mind on with respect to whatever it is that I'm trying to be creative with and it'll come to you. In this cruise control thing, there's some sort of coefficient that relates the threshold distance to however far it is. And I just couldn't figure it out. Like it's pretty intricate the way to assign all the loops and stuff and I just couldn't figure it out. I sat down and I stared at my computer for a half an hour and I couldn't do it and I got really pissed off. And then I just kind of left it. I walked around and I went out for a couple days. And eventually I was just like well, you could totally just do like this minus this and multiply that and it just all made sense. So I like kind of being out in the world thinking about her stuff and it just comes to you.”

His experience highlights the importance idea incubation when being creative in engineering work. Because engineering problems can be complex and difficult to solve, sometimes focusing on other things can help with looking at the problem later with fresh eyes.

Other students expressed that a distracting environment was not beneficial for creativity, giving preference to a quite environment where it was easier to focus. Althea described her preferred creative environment, “it has to be quiet with just the people that want to be there or that like want to come up with ideas. If you want to socialize, don’t be a part of this conversation. Like everybody should be there for the same reason, to come up with ideas. That way you don't get sidetracked.” Her remarks indicated that when students get distracted in team meetings, it derails
the focus of the other group members and the creative effort of the group suffers. Stella also preferred an environment free from distractions, “when I’m trying to come up with a creative solution to a problem the first thing that I like to do is more so isolate myself. Put myself in a quiet place in which there is no distractions. I find it very hard to be creative and kind of think of different solutions when you are in a very distracting environment, a loud environment.” For these students, distraction was detrimental to their creativity. Instead, they required minimal distraction so they could focus on the task at hand. Though students had different interpretations of what constituted a relaxing and effective work environment, they all agreed that being stressed was not conducive to creativity.

4.3.5.1 Limitations

The major limitation identified in this theme was the lack of authentic effort when being creative. Some students pointed out that success with applying creativity to engineering work required authentic effort from the students. However, some of these students explained how it was relatively simple to fake the creative effort. Many students attributed the lack of effort to creativity not being valued by their instructors. Students had this perception because it was rarely assessed and did not have high return for time invested.

Stephen explained how he would have liked to be more creative with his designs but his available time was the overarching factor that reduced his creative effort, “it would be nice to really take the stuff that we're learning and make an honest effort and really maybe get through multiple cycles of the design process but with all the other courses and all the other time commitments we have it's just not possible. It's always really easy to kind of half ass it and not give it the full attention.” He continued to explain an approach to making it seem that a genuine effort was put
in to produce a creative design, “you kind of work backwards and try to justify why you picked the easiest [solution] without saying you picked the easiest one because we don't have time to explore some of the more complicated ones.” Rueben also described his approach to faking creativity:

“I found that a lot of the times if it says brainstorm 10 ideas and then choose your best idea and go with it, I'll choose an idea, go with it, and then choose nine stupid ideas after. It's pretty easy to just come up with other things, especially when you're not trying to beat something. I'm willing to go off of a worse idea because there's no disincentives. I'm probably just going to do that if I'm busy, tired, and overwhelmed.”

These remarks shed light on how students tend to focus on the final result or solution as opposed to the approach and process used to solve the problem. It also illustrates how students can relatively easily “fake” the creative requirement in order to be efficient and choose a relatively easy path to fulfill a project requirement.

It was common for students to attribute the lack of authentic effort with being overtired and academic burnout. By her fourth year, Scarlet explained how she felt less passionate about her education:

“often I get really bored in school. I used to love school and I think it's because I had more energy. Things were more exciting and I don't know. I felt like I had more energy and I think I felt a little more hopeful about the things that could be accomplished and now it's sort of like you're just trying to produce as much work as you possibly can. So like you care that it's correct but you don't care if it's done as well as you could do it. You just care that it's good enough because I mean you want to sleep at night.”

Similarly, Cassidy said that by her fourth year she felt “disillusioned.” She continued to mention how this outlook has changed towards the end of her engineering education experience, “but I also have done four years and I'm really tired right now.” From the tone of the interviews, particularly with the students in senior years, it was evident that academic burnout was an important limitation because it had a significant impact on the effort students put into creativity.
Students are so focused on getting through and meeting expectations that anything that is not directly assessed and rewarded with marks is put at the bottom of their priority list.

**4.3.5.2 Discomforts**

Several students noted that confidence and self-efficacy with creativity skills was important for generating a creative design. Students had mixed responses when asked about their self-confidence with being creative in engineering. Some felt their creativity skills were excellent and they had no trouble when being creative in their work. However, other students felt that they were so used to solving rote problems that their creativity skills were not well developed.

An interesting response from several students regarding confidence in engineering creativity ability was how many engineering students are uncomfortable with creativity because they have a preconceived attitude that they are not creative. Althea made a point that many of her peers have predetermined that they are not creative because they pursued science and math subjects in high school rather than arts and humanities, “I hear a lot of people saying like, ‘I'm not creative. I can't. Like I'm not creative. I can’t do it.’ And then they’re like, ‘I'm really good at math but I can't do any art.’ It's not like art is bad, it's just they don't believe they can do it.” Althea’s point was supported by Jed’s response about his expectations for creativity before entering his undergraduate engineering program, “I wouldn’t really say I had much of an expectation. Yeah it didn’t really cross my mind to honest.” His comments highlighted how students entering university typically do not see how creativity fits into engineering.

Another common challenge identified by several students was how group work impacts the open-minded approach. Rueben said that successful groups need to consider all ideas without bias and
not immediately shut down ideas, “I think that if you're in a group where you know that your ideas won't be ridiculed and won't be shot down that's a big thing.” Charlie discussed his experience in one of his first year engineering design projects where being open-minded had a positive impact on his project and team experience:

“me and my robot buddy, we’re both in applied math and we’re both eccentric and into computers and stuff like that. So it's crazy, like we really reinforced each other. But whereas if you have like noncreative people or they kind of want to follow the bounds of the project a bit more. So it can be very tough. Like you know people are just going to shoot you down. But if you have another creative person then it's like ridiculous how helpful it is.”

Bertha explained how working in a group can be problematic if the majority of the group has no interest in the project, “I think it's harder when you're in a group setting because like I said before it's kind of up to your interest to go outside the box and you know do the extra research. So if only one person wants to do it, if it's only up to them, it's much harder as opposed to if everyone splits it up.” Althea had a similar feeling, stressing that negativity in a group will outweigh positivity, “they do have a negative attitude. I don't think they mean to portray it but they're usually the ones that say, ‘I can't do this.’ So when ideas are being made, they don't shut them down but they just don't care. Anyone with a negative attitude will outweigh anyone with a positive attitude.” Many students recalled occasions where group work was detrimental to the creative output, as well as instances when group work enhanced the creative output.
Chapter 5

Discussion

The analysis presented in Chapter 4 was used to respond to the research questions outlined in Chapter 3. These questions were:

1. What are students’ attitudes towards engineering creativity?
2. How do engineering students understand and experience creativity in engineering education?

In this chapter, quantitative and qualitative data were combined to describe trends and group differences while providing deeper insight and potential rationalizations of the observed results. Sub-questions were answered within the discussion topics. Also included in this chapter is a section explaining the limitations of the study.

5.1 Student Attitudes Towards Engineering Creativity

The primary attitudes investigated in this study were value for engineering creativity, time available to be creative in engineering work, and association with creativity stereotypes. Basadur and Hausdorff argued that these attitudes were important to measure because they influenced engagement in creative behaviour [45]. Additionally, the qualitative exploration into student perceptions towards creativity revealed that motivational attitudes were an important point of focus for engineering students, many of which can be traced to these three overarching attitudes.

5.1.1 Value for Engineering Creativity

Survey responses indicated that students generally had a high value for engineering creativity. The mean values for this factor, which can be seen in Table 11 in Section 4.2.2, were consistently high across all groups of interest which were gender, year of study, engineering discipline,
preference for problem solving, and confidence in creative ability. However, analysis revealed that students in Year 4+ had statistically significant less value for creative than all other years. These results suggest that students may lose value for creativity as they reach their final year of their engineering education. Though the survey could not be used to determine causation of these results, the interviews with senior engineering students lent insight into potential reasons for this difference.

Many of the senior students expressed feelings that embodied academic burnout. Cassidy stated that she had, “done four years and I’m really tired right now.” Scarlet commented that, “you get kind of tired too as you go through school and so it’s sort of hard to be as passionate about coming up with all these really weird or cool solutions.” Both of these fourth year engineering students felt that the extra effort required for creativity became more difficult towards the end of their engineering education. Several studies in the education higher education literature negatively correlate academic burnout with engagement in learning [90] [91]. These finding imply that engineering students become disengaged in their final year of engineering education when they are supposed to gain authentic engineering experience through Capstone projects or similar design courses. It is important to note that the effect size for this difference was small, yet academic burnout was a distinctive feeling expressed in the interviews by students in senior years of study.

Results also indicated that there were statistically significant differences in value between students who preferred open-ended and close-ended problem solving, or had no preference for either. Students who preferred open-ended problem solving had more value than both students who were neutral and students who preferred closed-ended problem solving. The instinctive
connection between preference and value made these results intuitive, as creativity was identified as being manifested in open-ended engineering design. These results support findings by Forbes who found that confidence in creativity was largely correlated to enjoyment and value for creative activities [92]. These results had a medium to large effect size, suggesting that preference can potentially be used as a predictor of value for engineering creativity.

For confidence in creative ability, students who reported having higher confidence had more value for creativity than those who were neutral or not confident. This indicated that confidence and comfort with creativity only had an impact on value when it was high. Though students did not explicitly make the connection between confidence and value in the interviews, it was clear from the tone of the interviews that students who were confident spoke more positively about engineering creativity than those who felt less confidence. Table 28 outlines quotes from the interviews categorized by their self-identified confidence in creative ability.

Table 28: Comparison of quotes between students with high confidence and low confidence in creative ability

<table>
<thead>
<tr>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>“They encouraged [creativity] that way and it’s usually through like extra marks.” - Cherise</td>
<td>“I personally think that it can sometimes negatively impact your grades.” - Bertha</td>
</tr>
<tr>
<td>“we’re presented with such a huge range of tools and skills and processes and ideologies and things like that I think just... like they do really help.” - Cassidy</td>
<td>“They’re trying to teach you proper way to tackle an engineering problem [creatively], but I don't know if it’s a very effective up to be honest.” - Jed</td>
</tr>
<tr>
<td>“I find it the coolest thing ever.” - Charlie</td>
<td>“Usually I zone out when they start saying creativity.” - Althea</td>
</tr>
</tbody>
</table>

In the literature, Zhou has shown that creativity training, nurtured through project based learning, can increase the confidence students have with their creative abilities [35]. In this study, increased confidence has been shown to have a medium effect size on the value students have for engineering creativity.
An interesting result from the one-way ANOVA for confidence in creative ability was that students who were neutral to problem type had statistically significant less value for creativity than students who preferred closed-ended problem solving. The reasons for these results are unclear and the interviews did not particularly lend any insight into this unexpected result. Because of this lack of engagement, the value for creativity diminishes. Schaufeli et al. found that reduced engagement was correlated with reduced value [91]. It is also possible that this result was caused by a Type I error (false positive), as the conditions for one-way ANOVA were violated for this test group.

5.1.1.1 Industry Value vs. Academic Value

Though the surveys indicated that students have high value for engineering creativity, the interviews lent deeper insight into this sense of value. Many students commented that they personally valued creativity, but felt their instructors did not. These students felt that as a skill, creativity was beneficial but creativity in academia was not. Students made comments including, “I don’t believe it’s something that’s very much valued,” and “it’s not something that’s explicitly put out there or promoted by a lot of professors or instructors.” The distinction between industry value and academic value was common throughout the majority of interviews. These findings were similar to Kazerounian and Foley’s who concluded that students demonstrate value for creativity, but their professors do not share the same sense of value [32].

These attitudes were grounded in the way students perceived their expectations from their instructors. The focus on correctness and the expectation of generating a standard solution to open-ended problems discouraged creativity from students. Scarlet noted how her feedback influenced her focus on being accurate with her design solutions, “like is your design going to
work or this is wrong? Less so on the innovation aspect of it I think.” Rueben commented that, “generally there's the standard path that you should be taking.”

It was clear that students had value for engineering creativity in an industry context because it was often identified as a useful and employable skill. Jack commented that, “[creativity] is kind of part of our thinking process when we get into the workforce.” Scarlet said that creativity was something that was, “going to help you design in the future.” These are two of many excerpts where students acknowledged the importance of creativity in engineering. Though the survey responses indicated high value for engineering creativity, the interviews helped clarify the intricacies of how engineering creativity is valued by undergraduate students.

5.1.1.2 Creativity is not Assessed
Most students attributed the mindset discussed in Section 5.1.1.1 to the lack of assessment of creativity in engineering courses. Though some students mentioned that creativity could contribute as a bonus mark, it was generally expressed that creativity was not a distinct assessment criterion. Berglund et al. determined that assessment was such a powerful tool that it had a large influence on how students approached their work. Furthermore, they determined that approaches to assessment had the capability to suppress creativity [46]. The results from this study corroborate these findings. Students made remarks such as, “we will often go with things that are less creative and things that have been done before or more familiar because you know it's going to work in the end and that's mostly what is assessed,” and “take the simplest route and not sort of try different things... You know, not seeing a reward for the effort put in.” Grades was a prominent topic throughout all interviews and lack of assessment of creativity was a clear barrier to the creative process.
A consequence from the absence of assessment for engineering creativity was the potential lack of authentic effort for being creative. Some students explained that since creativity was not a distinct assessment criterion of their final results, it was easy to “fake” the creative process and not take it seriously. Rueben said, “I’m more likely to take shortcuts there when you feel like you can kind of fake the creativity... Especially when it's not the kind of tasks where the most creative idea wins.” Stephen also articulated this connection, “you kind of work backwards from there and try to justify why you picked the easiest one without saying you picked the easiest one... There's a pressure to get to the end of the project and that's very counter to being creative because you're expected to get to a certain point to earn your marks.” The analysis highlighted the importance of assessment as a motivational and accountability factor for encouraging an honest effort at creativity.

5.1.1.3 No Feedback on Creativity

Students noted that feedback was an important indicator of what their expectations were and how to improve their designs and approaches. All student who were interviewed agreed that feedback on engineering creativity was extremely limited and mostly absent. This was clear from comments such as, “you get much more feedback regarding the technical aspects of your design like the feasibility,” “I don't think we get specific feedback on how creative our design is,” and “I don't think we usually get very much feedback on our creativity.”

Some students emphasized that the focus of the feedback, when received, tended to be on report formatting and feasibility of design solutions. In order to encourage creativity in engineering education, it was clear that students felt their feedback needed to shift focus from correctness and process, as well as being more tolerant of mistakes that are inevitable when attempting something
unfamiliar. Several studies support this shift in focus and highlight the importance of feedback for facilitating understanding and competence in the design process [93] [94].

5.1.2 Time for Engineering Creativity

Overall, survey responses indicated that students were impartial with respect to having enough time to be creative, with a slight tendency towards feeling that time did not inhibit their creativity. In Badran’s paper on enhancing creativity in the engineering curriculum, he noted the importance of having enough time to assess problems and think about potential solutions [28]. Correspondingly, Kazerounian and Foley identified time for idea incubation as one of their 10 Maxims for Creativity in Education [32]. In the context of this study, it appeared that time was not a barrier to being creative for engineering students.

There were no differences in these results across gender, year of study, and engineering discipline, however testing identified statically significant differences in the preference and confidence groupings. Students who reported confidence in their creativity skills felt they had more time for creativity than students who were not confident in their creative ability. This result was logical, as students who have confidence in their skills will be able to accomplish a task more quickly than someone who does not have confidence. The difference had a medium effect size.

The post-hoc testing also indicated a significant difference between students with a preference for closed-ended problem solving and students who preferred to solve open-ended problems. As was expected, students who preferred to solve open-ended problems felt they had more time for creativity than those who preferred closed-ended problems. This was not surprising because students who prefer to solve open-ended problems, problems which generally require more time, will be willing to put in the extra time commitment. On the other hand, students who are more
comfortable with closed-ended problems may favour quickly following the prescribed procedure to solve the problem as efficiently as possible.

Conversely, the results from the interviews and open-ended survey questions indicated that the majority of students felt that time was one of the most impactful barriers for creativity. Interview comments included: “in engineering you’re so busy,” “one of the biggest challenges is time,” “the biggest challenge is do I have time to actually be creative,” and “it is also so dependent on the time that you have.” As well for the open-ended survey items, 34.0% of students indicated that time was the most common challenge when trying to apply creativity in engineering work. In accordance with the interviews and open-ended survey responses, many studies in the literature have found that time for creativity is one of the largest perceived barriers to creativity [95] [96] [56].

To explain this discrepancy, it was possible that survey responses were influenced by social expectations and norms, where students tended to answer more positively about the time they had available for creativity in engineering. Because of the emphasis placed on time by all students in the interviews and in the open-ended survey questions, it was clear that time for creativity was a distinctive barrier to creativity.

5.1.2.1 Workload Does Not Allow Time for Creativity

The heavy workload in undergraduate engineering was the reason students attributed to the lack of time for creativity. There were several comments on how the workload was so overwhelming that deliverables became a non-stop checklist of items to complete, without having the ability to stop and think about the work that was being complete. Jed said, “you’re focusing on checking...
things off the to do list and instead of taking the time to do a project well.” Scarlet’s remarks also
illustrate this attitude towards workload and creativity, “we don't have a lot of time to do these
assignments because there's always so many for different courses.” A result of the heavy
workload was that students prioritized time and effort based on the reward. This finding is
detailed in Section 5.1.2.2.

In the literature, a study by Kyndt et al. investigated the impact of workload on engineering
students and concluded that perceived workload was largely influenced by interest in the work
and time management abilities [97]. Kember also resolved that perceived workload was largely
dependent on interest in the work and motivation for creativity [98]. This suggests that effort
needs to be put into engaging engineering students in their work. It can also be inferred that
engineering students may need to improve their time management skills. With modern access to
information, finding information is much easier and less time consuming which should result in
more time for developing skills such as creativity.

5.1.2.2 Time for Value
The interviews revealed that students seemed to make internal calculations on the return for time
investment. In this sense, students viewed their time as a commodity and valued marks as a
reward. Students made calculations on the marks they can potentially receive for the time they
invest on a given course deliverable. This phenomenon was observed by Garmendia et al. in their
investigation of how workload affects dedication to learning. They found that students typically
defaulted to following the regiment of a 40-hour work week, and adjusted their time investment
based on the number of lecture and tutorial hours each week. A strong correlation was also
observed between assessment and time investment [99]. Because creativity was rarely assessed or
rewarded, students felt that time investment for being creative had a low rate of return in marks, ultimately resulting in reduced value for creativity.

5.1.3 Creativity Stereotypes
From the survey, students tended to slightly disagree with typical creativity stereotypes. These results were consistent across all test groups, however group differences were identified between gender, where males identified more with creativity stereotypes than females. Basadur and Hausdorf argue that individuals who identify with engineering stereotypes are less likely to genuinely engage in creativity [45]. This suggests that male students are more likely to have difficulty being creative because they ascribed to conventional creativity stereotypes, however the effect size of this difference was small.

5.1.3.1 Engineering Creativity Misconceptions
Comparing survey results with the one-on-one interviews, students did not identify with the creativity stereotypes that were used to develop the items for Factor 3. However, other misconceptions emerged through the qualitative analysis. These stereotypes were related to the essence of engineering creativity rather than traits of creative individuals.

The first misconception was that creativity was only relevant for product design. Students admitted how they struggled to find the relevance of creativity in areas of engineering that were process based. “I find it hard to figure out how to connect creativity to a chemical engineering process.” Furthermore, some students extended focus on creativity in product design to the connection between creativity and entrepreneurship. They explained that businesses need a product to sell, and having a creative product helps with standing out from the competition.
The second misconception was that creative ideas need to be complex. Scarlet commented how she often had the attitude that creative ideas needed to be detailed and intricate, “it's too complicated. We don't really know how it works. It's weird. It's never been done before.” Because of her lack of knowledge and discomfort with the complexity of new ideas, she avoided pursuing creative options, reverting to a familiar solution that was more comfortable. With this attitude, Scarlet neglected ideas that were potentially creative in their simplicity and efficiency.

Thirdly, there was evidence to suggest that some students felt engineering creativity entailed generating ideas that were crazy and seemed unfeasible. This was apparent in comments such as, “brainstorming crazy ideas,” “I ended up doing like a weird thing,” “the wacky ideas you come up,” and “just crazy ideas.” There are two possible consequences that result from having in this attitude. The first is that students may disregard strange ideas because at first they do not seem possible or realistic. The second is that creative ideation will only focus on new and strange solutions rather than building off of existing ideas that have been proven to work. In both cases, the literature indicates that creativity will be limited by these misconceptions [41].

5.1.3.2 Predetermined Inability to be Creative

A common topic discussed in the interviews was the preconceived notion that engineering students who are not artistic or who do not have stereotypical creative ability do not have the capacity to be creative in their engineering work. Althea said that her initial mindset to creativity was, “you come in thinking, ‘I can't do it.’” Cassidy focused on the connection between artistic ability and perceived engineering creative ability, “they predetermined that they are not creative because they are not artistic.” Though art students have been shown to have more general creativity and artistic creativity, Charyton and Snelbecker found that there was no difference in
scientific creativity ability when compared with engineering students [100]. This suggests that even though engineering students may not have artistic capability, it should not deter them from engaging in engineering creativity.

5.1.4 Motivation to be Creative
The qualitative analysis identified important motivational factors that contributed to attitudes towards engineering creativity. These motivational factors can be explained through Expectancy-Value Theory, which states that motivation for learning requires validation of their personal expectations towards a task, as well as finding value in the content or skill [63].

5.1.4.1 Creativity Needs to be Rewarded
All students expressed that creativity needs to be motivated by awarding marks. Stephen said, “to encourage creativity, the most obvious answer is to reward points for it or marks.” Scarlet also explained that, “if you make it for marks everyone will have to do it.” The focus on marks aligned with extrinsic motivating factors and is supported by education literature that declares extrinsic motivating factors can be used to promote engineering creativity [37] [28].

From the interviews and open-ended survey questions, it was clear that reward for creativity was the main constituent of the value in the Expectancy-Value Theory on motivation. Assessment was identified by 21.7% of students in the open-ended survey as a current barrier to creativity, and most students acknowledged that creativity was not rewarded because there was no genuine expectation for creative solutions. It was clear that in order to promote engineering creativity, students need to receive marks for their creative efforts, finding that are supported by Badran and Berglund et al. [46] [28]. Without assessment of creativity, students may have difficulty engaging with creative in their course work.
5.1.4.2 Creativity is a Useful Engineering Skill

All students felt that creativity was important in engineering because it was a necessary skill to be able to solve new and evolving problems. This feeling was expressed in a variety of ways that lent insight into how students perceived the role of creativity in the field of engineering. Some students, including Rueben, felt that creativity was needed because old jobs become automated or unnecessary, “I think that going forward all of the jobs and careers that people will be doing that don't involve creativity, they're just going to go down in importance because with the rise of technology so many jobs become obsolete.” Stella had another common attitude which was that creativity skills were needed to solve both persistent and generational challenges:

“there’s going to be problems that exist that keep being persistent throughout each generation but each generation is going to face something new. Hence, it’s not going to be something you necessarily know from analytical math and analytical science, theories that are already existing. It’s something that someone somewhere will probably have to come up with a very different approach to the problem. So I believe that in engineering education [creativity] is very crucial to have.”

The expectation that creativity is a useful and employable skill is the second piece of the Expectancy-Value Theory. In addition to being rewarded for their creativity, students also need to be able to see how creativity skills are applicable in the engineering field. If students understand that being creative will improve their grades, and they are exposed to various examples of creative engineering, they may become more motivated to take a deep approach to learning and developing their creative abilities.

5.1.4.3 Creativity Requires Passion and Interest

Many students explained how passion and interest in the project was an important motivational factor for creativity. In recalling their experiences with creativity, some students discussed that creativity came naturally when they were enthusiastic about the project. Charlie cited one of his
design project experiences, “we had a really good time with it and that's a good creative application.” Other students mentioned how passion was a key characteristic of creative individuals. Scarlet stated that creative people are, “people who have a lot of energy and passion.” Similarly, Cherise said, “usually they're very enthusiastic.” It was apparent that interest and passion had a large impact on student engagement in design projects and creativity.

Passion and interest also contribute to the value portion of Expectancy-Value Theory. Though extrinsic value was dominant, the intrinsic value associated with enthusiasm can also influence motivation for being creative. Bjorner and Kofoed’s found that teachers agreed with the importance of finding relevant projects that students were passionate about to promote students’ creative efforts [27].

5.2 Students’ Understandings and Experiences of Engineering Creativity

The results in Chapter 4 indicated that understanding and experience of engineering creativity were intertwined, with understanding informing experience and vice-versa. Student understandings were captured in the way they defined engineering creativity. These definitions were largely influenced by their recognition of opportunities for creative experiences in engineering education, primarily in engineering design projects.

Students also discussed their perceived expectations from instructors when it came to being creative with their course work. This theme contained elements of both experience and understanding. Students recalled their personal experiences with academic expectations while explaining how their instructors defined engineering creativity through these expectations.
The interviews provided a rich description of how students felt that opportunities for creativity were limited in engineering education. Discomforts with creativity was also a common experience described in the interviews.

5.2.1 Students Experience Engineering Creativity in Open-ended Design

From the interviews and open-ended survey questions, it was clear that students primarily experienced engineering creativity when engaging in design work, particularly when design work was open-ended. Design language was used consistently throughout all interviews, “idea generation”, “design courses,” “open-ended problems,” “multiple solutions available,” “explore multiple designs really thoroughly,” “brainstorming, mind mapping, and SCAMPER,” “evaluating the solutions,” and “iterate and ideate,” and “feasibility, risk, and safety.” A total of 89.2% of students reported that they experience creativity in their design courses. Accordingly, Christiaans and Venselaar found a relationship in design knowledge and creative output [4].

5.2.1.1 Group Work

When students discussed their experiences with creativity in engineering design, they all commented on how their engineering design work was almost always done in teams. In contrast to the literature, Haungs, Clements, and Janzen found that a barrier to creativity amongst first year engineering students was that they felt creativity was an individual endeavour [101].

Students commented that group work had both advantages and disadvantages, the most prominent of which are displayed Table 29.
The most recognized advantage of being creative in teams was having multiple perspectives for generating different solutions to the same problem, as well as evaluating and building off of those ideas. Jack commented, “once they, or I, or anybody proposes an idea then you can expand on that and bounce ideas off of that.” Cherise mentioned how she liked to talk out her ideas with her peers, “I bounce these ideas off other people and I can see what they think of them.” Students also mentioned how working in teams helped with accountability. Jack said that he felt it was his responsibility to put in the same effort towards creativity as his other teammates, “I guess one aspect is accountability in a way. Like if I’m by myself I generally wouldn’t come up with creative ideas.” In the literature, group work has been shown to aid with creative processes because of the benefits from having multiple perspective from different team members [90]. However, some students noted how accountability can play a negative role. Students did not want to put in the extra effort to be creative if their teammates wanted to take the standard path instead of making a genuine attempt at creativity. These students typically shut down creative ideas quickly and discouraged creative problem solving. Scarlet mentioned that she had this experience where she was a TA for a design course, “there’s this one guy who has been telling the other students that their ideas are stupid or completely shutting them down.” Some students also noted a fear of looking stupid by proposing crazy ideas that might not seem realistic or feasible. Based on these finding, it was obvious that students felt team dynamics had a large influence on their potential creativity.

Table 29: Perceived advantages and disadvantages of group work on creativity

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple Perspectives</td>
<td>Discouragement from Teammates</td>
</tr>
<tr>
<td>Accountability to the Team</td>
<td>Negative Attitudes</td>
</tr>
<tr>
<td></td>
<td>Fear of looking stupid</td>
</tr>
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</table>

The most recognized advantage of being creative in teams was having multiple perspectives for generating different solutions to the same problem, as well as evaluating and building off of those ideas. Jack commented, “once they, or I, or anybody proposes an idea then you can expand on that and bounce ideas off of that.” Cherise mentioned how she liked to talk out her ideas with her peers, “I bounce these ideas off other people and I can see what they think of them.” Students also mentioned how working in teams helped with accountability. Jack said that he felt it was his responsibility to put in the same effort towards creativity as his other teammates, “I guess one aspect is accountability in a way. Like if I’m by myself I generally wouldn’t come up with creative ideas.” In the literature, group work has been shown to aid with creative processes because of the benefits from having multiple perspective from different team members [90]. However, some students noted how accountability can play a negative role. Students did not want to put in the extra effort to be creative if their teammates wanted to take the standard path instead of making a genuine attempt at creativity. These students typically shut down creative ideas quickly and discouraged creative problem solving. Scarlet mentioned that she had this experience where she was a TA for a design course, “there’s this one guy who has been telling the other students that their ideas are stupid or completely shutting them down.” Some students also noted a fear of looking stupid by proposing crazy ideas that might not seem realistic or feasible. Based on these finding, it was obvious that students felt team dynamics had a large influence on their potential creativity.
5.2.1.2 Product Development

The interviews revealed that students felt creativity was particularly relevant in product development. Students in engineering disciplines that were more process based, such as chemical engineering, or theoretical based, such as applied math and engineering physics, struggled to see how creativity was applicable. Scarlet stated, “I find it hard to figure out how to connect creativity to a chemical engineering process.” Rueben remarked, “in the pure physics courses that I’m taking [creativity] is not really relevant.” Both students agreed that creativity was more appropriate for disciplines such as mechanical and electrical engineering because they involved developing novel products. In Fila, Purzer, and Chakroun’s study on different perceptions of innovation held by different engineering disciplines, they confirmed that chemical engineers associate more with in-house processes while mechanical engineers saw creativity in bringing a product to the market [54].

The elements of product development that students commented on included being creative in understanding and addressing user needs and using modern technology or physical prototypes to demonstrate the features of their design. The focus on user and stakeholder needs had an obvious connection with entrepreneurship, as students felt a creative product was able to provide value to and attract consumers. Cassidy felt that, “creativity is important and it’s necessary to come up with new solutions that are valuable.” Similarly, Scarlet thought there was creativity in, “making it more interesting or more appealing to a consumer or user.” Students also felt that they were being creative when using modern technologies to create models or prototypes, including the use of CAD software and programming. Stephen explained that there needed to be a prototyping component to encourage creativity, “I was fortunate enough to be on a build design project, so
although it didn't work because it wasn't well designed, we did build a prototype and it did exist as a proof of concept for our [creative] idea which was cool to see.”

Overall, it seemed that students felt they were being creative when they were physically engaged and interacting with their designs, as opposed to developing them from a completely theoretical perspective. Bedard encourages teaching creativity with a hands-on approach. Though he accepts that there is a risk that students may revert to a trial and error process instead of using sound engineering design process, he claims that with proper open-ended project development and evaluation of theoretical understanding, creativity can be promoted using this pedagogy [102].

5.2.2 Opportunities for Creativity are Limited

When discussing their experiences with engineering creativity, many students acknowledged that the opportunities to be creative in engineering education were quite limited. This finding was determined from the survey where 20.8% of students responded that limited opportunities were the largest barrier to being creative in engineering education. As well, several students noted in the interviews that projects and assignments with creativity were lacking. Jed portrayed this sentiment, “I wouldn't say there's too much creativity going on to be frankly honest.” Students consistently drew on their experiences with creativity from a select few projects they had completed in their engineering education. These findings are consistent with the literature that says opportunities for creativity in engineering education are limited [2] [4].

Rueben pointed out that he was generally limited to one design course per semester and that his other courses did not have opportunities for creativity. The assignments and projects for his technical courses were usually closed-ended in nature. In consideration of Kazerounian and Foley’s 10 Maxims of Creativity in Education, many of the maxims such as keeping an open-
mind, iterative process, and search for multiple answers, are achieved through engaging students
in open-ended problem solving and project based learning [32]. This indicated room for
improving the creativity environment in undergraduate engineering education simply by giving
students more opportunities to practice and develop creativity skills.

Moreover, there were students who commented on how some their projects had the illusion of
creative. Cassidy described this as, “the veil of creativity.” She continued to explain that, “those
projects didn't really give an opportunity for completely open-ended thinking and problem
solving because you couldn't do that.” By this she meant that instructors may have had the
intentions of allowing for creativity in their projects, however in actuality the projects were not
open-ended enough to allow for true creativity.

5.2.3 Student Definition of Engineering Creativity

Data on student definitions of engineering creativity were gathered by the open-ended survey
questions and the one-on-one interviews. Similar to the literature, engineering creativity
definitions were varied but also shared many common elements [12] [13]. Upon analysis of the
survey responses, students provided definitions that included a creative action followed by a
description of a creative characteristic. The categories that emerged from the qualitative analysis
of the interviews also fell into themes of action and characteristic. Accordingly, Feldhusen and
Goh assert that definitions of creativity require both a cognitive activity, the creative action, and a
description of a creative outcome, the creative characteristic [103].

5.2.3.1 The Creative Action

From the open-ended survey results, the most frequently identified creative actions were problem
solving and idea generation. Other actions included critical thinking, designing, and modification.
These responses were noteworthy because they are all common terms used in engineering design language, strengthening the evidence of the association that students make between creativity and design [52]. From the emphasis on ideation and lack of recognition of creativity in other stages of the design process, these results show that the students felt creativity was most prevalent in the early parts of the engineering design process. Bjorner and Bruun-Pedersen similarly found that students felt they were more creative in the early stages of the engineering design process [51].

From the interviews it was evident that students felt creativity was manifested through engineering design work. The depth of information obtained from this data collection phase of the study revealed that students do in fact see creativity in many different aspects of the engineering design process. However, these comments were not consistent throughout all the interviews. What remained consistent was that the definition of creativity involved idea generation. Table 30 displays different creative action from the interviews.

**Table 30: Creative actions in engineering design**

<table>
<thead>
<tr>
<th>Action</th>
<th>Quote</th>
</tr>
</thead>
<tbody>
<tr>
<td>Idea Generation</td>
<td>• “brainstorming”&lt;br&gt;• “coming up with ideas”</td>
</tr>
<tr>
<td>Understanding the Problem</td>
<td>• “creativity happens in discovering the problem”&lt;br&gt;• “you’ve got to check out your stakeholders and your problem definition”</td>
</tr>
<tr>
<td>Modification</td>
<td>• “adapt your ideas and take other people’s ideas and combine them”&lt;br&gt;• “looking at something that has already been done and adapting it for your needs”</td>
</tr>
<tr>
<td>Idea Selection</td>
<td>• “narrow it down to five and then finally narrowed it down to one”</td>
</tr>
<tr>
<td>Idea Evaluation</td>
<td>• “creative thinking in how you’re supposed to evaluate your designs”&lt;br&gt;• “ways of whittling down those ideas, so again there’s evaluating them”</td>
</tr>
<tr>
<td>Design Iteration</td>
<td>• “figure out something that works using iterative processes”&lt;br&gt;• “refining your ideas after you’ve chosen one”</td>
</tr>
</tbody>
</table>
5.2.3.2 The Creative Characteristic

Novelty and uniqueness were the most common characteristics associated with creative solutions. This was consistent in both the open-ended survey responses and student interviews. The interpretation of creativity as creating things that are new and original is aligned with classical definitions of creativity in the literature [16] [19]. This understanding of creativity can be problematic because students may get overwhelmed with the complexity of creating a brand new design, as some students acknowledged lacking the technical skills to be creative, “the problem with [creativity] is that people don't usually understand it enough to be able to take that open-ended problem and go, 'OK. Here's the direction I want to go with it.'” Sternberg noted that this misinterpretation of creativity can put unnecessary pressure on students [14].

To a lesser extent, students identified creativity characteristics that were context-specific to engineering including being unobvious, functional, and improvement. These factors, particularly functionality and improvement, are more aligned with engineering specific creativity. Many researchers have recognized the importance of effectiveness of a solution in the context of engineering [27] [11].

An interesting contrast found in the open-ended survey responses was that some students identified creative ideas as being complex and others felt creative ideas exemplified simplicity. Similarly, in the interviews there were some students such as Cassidy who felt that the elegance of simplicity required creativity, “you could also look at [creativity] in the sense of simplicity”. On the other hand, Stella expressed that creative solution needed to be complicated enough to stand out, “it should be more complex maybe in the design, showing certain skills to an
exceptional level.” This comparison highlights some of the inconsistencies with engineering creativity definitions.

5.2.4 Perceived Expectations of Students by Their Instructors

It was evident from the interview data that students adapted their approach to learning and completing deliverables based on how they perceived their instructors’ expectations. Two overarching expectations were identified. The first was that instructors were most concerned with students getting accurate results. The second was that students typically take standard approaches that are safe because of the difficulty of being both technically accurate and creative.

5.2.4.1 Obtain Correct Results

The common sentiment from students was that they were expected to be correct with their designs and results. As well, they emphasized the importance of being able to justify the logic used in making design decisions. This meant that students felt their instructors expected them to produce designs that were feasible and supportable using accurate science. Students explained that being creative and taking the risk of not coming up with accurate or complete results was not worth it because their instructors’ expectations of correctness. Stephen commented, ‘‘what happens if in being creative I end up at this place where I don't have anything. And then where does that leave me in terms of marks?’’ His concern was shared by several of the students that were interviewed.

These findings support research by Toh and Miller who studied how engineering students select design ideas. They discovered that creativity is rarely considered in the idea selection phase of design process, rather students place their concern on the feasibility of the design. They noted
how students were driven by satisfying the design goal and were hesitant to take any risks that may result in a failure to meet those goals [104].

5.2.4.2 Take the Obvious Approach

Students felt that many of their instructors did not actually call for creativity in their course deliverables. The time required and the difficulty of coming up with new and creative solutions was not generally expected. Students explained that because it was possible to obtain high grades by producing a standard solution, their instructors did not anticipate students to go beyond an obvious design and generate a creative design. Charlie said that he was trying to come up with a creative design for a project and his TA was, “confused that I [was] not doing a [standard] type thing.” Scarlet cited one of her experiences where her classmates worked hard to be creative with their design, yet students who chose to go with the provided design received similar marks, “I don’t think they were rewarded for being creative with their own ideas whereas the rest of us kind of got away with using something that was given to us because it was easier in the end.” These findings support results from a study conducted by Bjørner and Bruun-Pedersen. They found that students felt their instructors understood the workload and time available to work on each course and adjusted their expectations accordingly [8].

5.2.5 Students Experience Discomfort with Creativity

A clear thread woven throughout the themes in the qualitative analysis was the discomfort students associated with creativity. Discomforts were attributed to various factors, which were, in essence, barriers to creativity. Students experienced the barrier of limited experience with engineering creativity which caused a lack of confidence and discomfort with open-ended design. The second barrier was the difficulty of assessing creativity. The reason engineering creativity is challenging to assess is because of different interpretations and definitions of the construct [43].
Students shared a related feeling of discomfort with creativity because of the ambiguity and subjective interpretations of their work.

5.2.5.1 Limited Experience

Though most students in the survey responded that they were confident in their engineering creativity abilities, the interviews suggested that the lack of opportunity for being creative resulted in limited experience with open-ended problem solving and engineering creativity, causing a lack of confidence and discomfort with engineering creativity. Students identified different types of discomforts, some which were associated with trying something new and different, and others that were related to the communicating engineering design work.

Some students felt that because their curriculum was focused on technical courses, when they were asked to utilize the engineering design process to solve open-ended problems they felt pushed out of their comfort zone. Bertha commented that, “it's a push for me outside my comfort someone when I’m trying to do [design projects].” Because technical courses generally teach standard procedures to solve closed-ended problems, students seem to have become accustomed to this expectation.

Another area that students expressed some discomfort was with writing reports. Students articulated a discomfort with creativity because they made the association between creativity and design, and their design courses typically require extensive design reports. It was noted by Bertha in her interviews that students select engineering because they are strong in math and science with writing being a skill, “communicating in an essay for me is a lot harder than it is to figure out math. And it's a push for me outside my comfort when I’m trying to do that.” Because
students associated creativity with engineering design reports, there was a distinct feeling of discomfort with expressing creativity in writing and report writing in general.

5.2.5.2 Ambiguity and Interpretation

There was a clear discomfort that students expressed with the ambiguity inherent with creativity. Two main types of ambiguity were expressed: (a) the possibility of multiple possible correct answers and (b) the subjective interpretation of creative solutions.

In the interviews several students expressed clear discomfort with solving problems that have multiple correct answers. Scarlet said, “I think that’s what actually makes a lot of students uncomfortable because they're like, ‘I don’t know if I’m doing it right because there isn’t a right answer.’” Stephen described his experience with creativity in engineering education, “just generally struggling with being creative in a science based field where I've been told that there's always the right answer.” Similar to the literature, Kazerounian and Foley noted that maxim associated searching for multiple answers was missing from engineering education [32].

Subjective interpretation of creativity was grounded in students’ focus on assessment. Students felt that they were often unsure of how their creative efforts will be interpreted by the instructors who were assessing their work. Stella was concerned, “what if the TA marking me doesn’t personally like that [solution]? ... Everyone is going to interpret it very differently.” Cassidy did not understand how it was possible to assess creativity with different evaluators, “everybody has a different idea of what a creative solution is. How are you assessed on that creativity consistently throughout the process by different people?” As a consequence, students showed signs of reverting to easier standard designs that they were confident would result in higher
grades. Rueben pointed out, “if I'm willing to go off of a worse idea and if there's no disincentives, then I'm probably just going to do that.” The difficulty of consistent interpretation and assessment of engineering creativity highlights the inconsistency in creativity definition and knowledge.

5.2.6 Students Experience Fixation

Some students articulated how they found idea generation difficult once they came up with an initial idea to a problem. Jack described one of his engineering design experiences, “we were a little bit too stuck in our ways. We had an idea of what we wanted to go with but I was just at the proposal stage.” Stella felt her past projects made it difficult for her to think of new alternatives, “you are thinking of all the past projects that you've done and it can be very hard to generate an original solution.” This phenomenon is known as fixation, and student experiences with fixation is well documented in the literature [60] [61].

In Daly et al.’s research on how first years perceive creativity in design ideas, they found that design tools can help engineering students overcome fixation and improve their divergent thinking. Responses from the interviews corroborate these findings, where many students stated that the design tools they were learning in design classes actually did help with idea generation and coming up with multiple solutions. Cassidy said, “we’re presented with such a huge range of tools, and skills, and processes, and ideologies, and things. I think like they do really help.” Many other students commented how they used creativity tools in their idea generation sessions for their design projects.
5.3 Validation Strategy

The validity strategy employed for this study was primarily triangulation. Using this approach, data on attitudes, experiences, and understanding of creativity were gathered using three different formats. Data was collected from closed-ended survey questions, open-ended survey questions, and one-on-one interviews. The questions for each of these instruments were designed to support one another and allow for corroboration or contradiction of results. Through triangulation, similarities and differences across survey and interview responses were highlighted.

5.4 Limitations

There were limitations in this study in both the quantitative and qualitative phases. The generalizability of the survey results had limitations with the sampling method and the data collection instrument. Interview data had inherent limitations with the interview selection design and the interpretation from myself as the research instrument and data analyzer.

5.4.1 Sampling Method

Because the sample was only from Queen’s University, the findings are only truly representative for this institution. Still, it would be reasonable to extend the generalizability of the results to other Canadian universities with research oriented engineering programs. However, it is important to consider the multi-disciplinary design courses that are mandatory for first and second year engineering students in Queen’s engineering programs where students are taught engineering design and professional practice skills.

Overall response rates were low, 17.1%, but typical of online surveys. Response rates by gender, discipline, and year of study were not proportional to the population, particularly with
engineering discipline. These response rates mean less of the population was captured in the results and limits the generalizability and confidence in the results.

There was potentially some bias in the recruitment of students for the survey. After the initial data collection phase, stratification was completed by requesting permission from instructors to administer the survey or promote the survey in classes. Instructors of core courses were contacted, many of which were engineering design courses. It was possible that the instructors that responded positively had a higher value for creativity that was passed down to their students. Furthermore, it is possible that students who valued creativity were more likely to complete a survey on creativity in engineering education. The collection of survey data over time also needs to be considered in the interpretation of these results, as there is inevitable change in attitudes over time, particularly when in the process of learning the skills that have been deemed necessary for engineering competence.

5.4.2 Survey Instrument

The instrument was limited in the reliability. The Cronbach's $\alpha$ values for Factor 1 – Value for Creativity and Factor 3 – Creativity Stereotypes were less than the .7 threshold used in psychometric research (.69 and .66, respectively). Factor 2 – Time for Creativity was also borderline at .71. Additionally, Factor 2 and Factor 3 were only measured using three items each. More items could have helped increase the reliability of those factors. Overall, some caution needs to be taken when interpreting the results from this study because of possible limitations with the instrument.
5.4.3 **Interview Participation Selection**

Because students were selected randomly from a list who volunteered at the end of the survey, it is possible that students who were interested and had more value for engineering creativity were the ones who volunteered. This would have impacted the types of opinions that would have been expressed about creativity. Additionally, $15 gift cards were offered for interview participation which may have influenced both the type of students who volunteered and their actual responses. Interview recruitment and participation selection need to be considered with respect to the authenticity and trustworthiness of interview data.

5.4.4 **Researcher as the Instrument**

Qualitative research has unavoidable limitations because of the inherent bias from the researcher who acts as the instrument. Every effort was made to remain impartial and avoid leading questions. Any personal bias was clarified in Section 3.2.2.1, and should be considered when reviewing the analysis and findings.
Chapter 6

Conclusion

This study gave insight into how students perceive the creativity environment in undergraduate engineering education. Mixed methods were used to obtain both general and in depth descriptions of creativity attitudes, understandings, and experiences. Quantitative methods provided general trends in students’ attitudes towards engineering creativity, their definitions of engineering creativity, and the barriers they experience with being creative. Qualitative data offered a rich description of the understandings and experiences students have had with creativity in their engineering education. Results from both data types were combined to develop a thorough description of the creativity environment in undergraduate engineering from the perceptions of students. Overall, the various themes and attitudes that emerged in this study confirmed that creativity is a complex and multifaceted construct.

When considering the applicability and generalizability of the findings, readers should be aware of the context of the study and the demographics of the individuals who participated. Survey participants were limited to Queen’s University, and interview participants all had unique experiences with engineering creativity. Nonetheless, based on the commonalities between engineering programs, particularly because they are all accredited by Engineers Canada, the findings may be applicable to other Canadian engineering programs.

Both phases of the study confirmed that students had value for creativity, however there was a difference between valuing creativity as a useful and employable skill for engineers versus valuing creativity in an academic setting. While students valued creativity in the engineering
industry, most students did not feel that creativity was valuable in engineering education. This attitude was a reflection of their perceived expectations from professors and TAs, and the lack of assessment of creativity in many of their design projects. Students felt that instructors wanted them to follow the standard procedure and obtain the correct result. Creativity, if expected, was generally seen as a bonus that was not necessary to be successful.

There was a sense that students felt their instructors did not value creativity in their work, even if it was an open-ended design project with creative potential. This attitude was associated with the absence of assessment for creativity, or assessment of creativity that seemed arbitrary. Students equated their time to currency and wanted to maximize their investment with return in marks. Ultimately, students usually determined that it was not worth the extra time required to be creative because their efforts were not rewarded.

Group differences were identified for the attitudes of value for creativity, time for creativity, and creativity stereotypes. Students in Year 4+ had less value for creativity than all other years of study. Also, students who preferred open-ended problem solving and were confident with their creative abilities had more value for creativity than their counterparts. Students with preferences for open-ended problem solving and positive confidence also felt that they had more time for being creative in engineering work. Males identified more than females with creativity stereotypes that reflected classical interpretations of creativity including disorganization and unconventionality.

In addition to assessment and lack of time, the other prominent barriers to creativity that were identified in this study were lack of opportunity, discomfort with the ambiguity of open-ended
design, and fixation. Students felt there were few opportunities to be creative in engineering education. The overwhelming majority of students responded in the open-ended survey that creativity was primarily present in their engineering design courses, and interview participants almost exclusively discussed experiences with design projects. However, students pointed out that these courses were limited, as their curriculum focused on technical courses with closed-ended problem solving.

Students felt discomfort with the ambiguity inherent with creativity. Open-ended design projects that challenged students to produce solutions when there were no correct answers made students uneasy. Their experiences in engineering education had made them used to solving closed-ended problems with single correct solutions. Students also recognized the subjectivity with the interpretation of creativity and how it made them uncomfortable with being assessed on their creative efforts. The variety of definitions of engineering creativity was evident from the open-ended survey results and interviews. An assortment of language was used to describe creative actions and creative characteristics. The majority, however, related creativity actions to design work and creative characteristics to classical descriptions of creative outputs.

Some students struggled with fixation when trying to generate creative ideas. Once they came up with a solution that seemed feasible, it was natural for them to stick with that idea. Further ideation became stressful and impractical. However, students felt that design tools helped improve the quality of idea generation, corroborating evidence in the literature of the benefits of design heuristics in the literature [40] [4].
When compared with Kazerounian and Foley’s study on the barriers to creativity in engineering education that were examined by, students identified difficulties with six of the 10 Maxims of Creativity in Education [32]. Lack of assessment was tied to rewarding creativity and learning to fail, and lack of time was related to iteration and idea incubation. Discomfort with ambiguity embodied keeping an open mind and understanding that ambiguity is good. Fixation was connected to the maxim of searching for multiple answers. This suggests that these barriers need consideration in pedagogical practices, and when developing engineering curriculums and educational policy. The remaining four maxims, (a) lead by example, (b) encouraging risk, (c) internal motivation, and (d) ownership of learning, were less emphasized or not identified at all by the students during the interviews. Because students did not focus on these maxims, it was unclear if they were absent from the creativity environment in engineering education or if the barriers associated to these maxims were less of a concern to the students.
Chapter 7

Recommendations

In consideration of the findings of this study, the following are recommendations aimed at promoting creativity in engineering education.

Many of the problems associated with engineering creativity are rooted in the numerous ways in which it is defined. Difficulty of assessment, recognition of opportunities for creativity, and discomfort with ambiguity, are all problems that can be solved by developing a clear definition of engineering creativity that is vetted and accepted by academics and industry professionals. The lack of an established comprehensive definition also makes academic research on creativity challenging because studies are difficult to compare and contrast, as researchers take different positions on what creativity means. There is a clear necessity for a universal definition for engineering creativity.

If instructors want students to make an authentic attempt at being creative with their designs, it needs to be rewarded with marks and formative feedback that is consistent with the application context. Having a clear definition of engineering creativity will help develop an instrument that can assess levels of creativity. It would be helpful to design an assessment tool that is quick to complete and easy to understand. This will increase the value students have for engineering creativity and increase their motivation. Daly, Mosyjowski, and Seifert implore that developing assessment to motivate engagement in engineering creativity is crucial for engineering pedagogy, as they found that current creativity assessment practices are either vague or lacking. They
suggest assessment tools should be designed to motivate students to improve their personal creative ability, and reflect on their creative process [4].

Two more recommendations that may help improve students’ motivation to be creative is to let students take ownership of their learning by selecting their own projects and by giving the students the opportunity to construct prototypes or simulations of their designs. Though freedom of project selection may be difficult, it was evident that when students were interested and passionate about their projects, they were more inclined to be creative. Therefore, to best of their abilities, it is recommended that instructors allow students to choose their project topics or challenges. This can include having multiple projects options, having students submit their preferences for different projects, or having students recommend their own projects. Kazerounian and Foley noted the importance that ownership of learning has on students’ motivation to engage in creativity in engineering education. They stated that giving students the freedom of choice in their projects can help increase intrinsic motivation for being creative [32]. However, complete freedom of selection needs to be considered with caution as projects need to be complex enough, fit within the learning objectives of the course, and be compatible with assessment tools.

Students also felt that they were being creative when they were building prototypes or creating simulations of their designs. Because of this it is recommended that time for prototyping be incorporated into course timelines. If possible, having extra resources allocated to the prototyping may encourage students to engage in the project. Silva, Henriques, and Carvalho argue that creativity can be enhanced by having students generate prototypes because it helps them understand that creativity can be applied at all stages of the engineering design process. By having a functional prototype, students can detect and solve unanticipated problems as they
progress from the initial to the final design. They claim that prototypes ultimately help students understand their product better and look at their product from different perspectives [105].

The differences with preferences for problem-solving indicated that students who preferred open-ended problem solving had a more positive attitude towards creativity and were therefore more luckily to engage in creativity. This suggests that students who enjoy open-ended problem solving might be successful as engineers and would engage to a higher level in the projects and learning process in engineering education. Because of this, it is recommended that preference for problem-solving be considered as a recruitment quality for high school students who are choosing university programs. Students who are strong in math and science and enjoy solving open-ended problems might want to consider pursuing an engineering degree.

Students need to be given more opportunities for being creative. This will help improve class engagement and open-ended problem solving skills. If students are consistently engaged with projects that require creativity, or even small classroom activities that stimulate thinking from different perspectives, they may gain confidence with being creative in their engineering designs. It would be valuable to carefully design open-ended engineering projects that promote engineering creativity throughout the entire design process so creativity is not isolated to the idea generation phase. By comparing the creativity with different projects over multiple years, a project bank can be created for instructors.

It would be beneficial to expose students to different creativity and design tools to help them overcome fixation. In the interviews, students noted the effectiveness of design tools which corroborated findings in the literature. Daly et al. submitted a similar recommendation because
they found that the creative output from engineering students increased when they were introduced to the Design Heuristics method for idea generation [41]. Teaching other creativity design tools, such as TRIZ, has also been recommended because of its impact on creative abilities and use in engineering industries [40]. Students who struggle with coming up with multiple ideas should be made aware of various relevant creativity tools, and where and how they can be applied.

These recommendations show how the findings from this study can be used for educational resource development. The conclusions can inform creativity modules and workshops, assessment tools, and student project designs. Additionally, the findings can inform the development of engineering curriculums that promote creativity, pedagogical approaches that emphasize creativity skills, and assessment tools designed to foster engineering creativity. By embracing the power of project based learning through engineering design, the facilitation of engineering creativity can be enhanced.
Chapter 8

Future Work

Suggestions for future work are advanced based on a review of the study’s research design and findings. To build upon this investigation into engineering creativity, it is necessary to improve the instrument used to measure attitudes, to address questions and points of interest that arose from the analysis, and to expand the scope to study to other populations.

8.1 Instrument Improvement

The instrument used to capture student attitudes towards creativity requires refinement to improve its reliability and validity. This can include increasing the number of items in each factor, altering current items to improve clarity, and including items to gauge and correct for effects of social desirability in the responses. Six items were removed from the analysis through the factor analysis. These items and suggested changes are listed in Table 31.

Table 31: Suggested changes to the interview questions

<table>
<thead>
<tr>
<th>Items</th>
<th>Associated Factor</th>
<th>Suggest Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creativity is primarily useful for large engineering projects.</td>
<td>Value</td>
<td>Creativity is useful for small, everyday engineering problems.</td>
</tr>
<tr>
<td>If everyone is providing ideas, no one gets any work done.</td>
<td>Value</td>
<td>Creativity causes distractions from focusing on results.</td>
</tr>
<tr>
<td>The instructor’s idea is usually the best since it comes from a much broader perspective.</td>
<td>Stereotype</td>
<td>People with more experience can come up with the most creative ideas.</td>
</tr>
<tr>
<td>All people have creative ideas from time to time.</td>
<td>Stereotype</td>
<td>Everyone has the ability to implement creative ideas.</td>
</tr>
<tr>
<td>Creative ideas seldom work out.</td>
<td>Stereotype</td>
<td>Creative ideas are difficult to implement.</td>
</tr>
<tr>
<td>Only smart, knowledgeable people have good creative ideas.</td>
<td>Stereotype</td>
<td>A strong background knowledge in science and engineering is required for creativity.</td>
</tr>
</tbody>
</table>
8.2 Causation of Group Difference

Future work should investigate the causation of the group differences found in this study. This should include why value for creativity was impacted by year of study, preference for problem solving, and confidence in creative ability. Two relationships should be further studied: (a) time available for creativity and problem-solving, and (b) time available for creativity and confidence in creativity skills. As well, it would be beneficial to investigate the effect of gender on identification with creativity stereotypes. Though the interviews did provide a deeper understanding of these attitudes and group difference, the findings from the interviews are not generalizable and require further inquiry.

8.3 Impact of Preference and Confidence in Problem Solving

An interesting finding was the impact that preference for problem solving and self-reported confidence in creative ability had on attitudes towards creativity. Though the literature indicates that there should be differences in creativity attitudes based on year of study and engineering discipline, preference and confidence stood out for Factor 1 – Value for Creativity and Factor 2 – Time for Creativity. Year of study only had small difference for value, and engineering discipline had no differences for any factors. It would be useful to investigate if preference and confidence are strong predictor variables for attitudes towards engineering creativity, and if year of study becomes a larger difference in a broader data set.

8.4 How Do Attitudes Impact Creative Ability?

Understanding how students perceive and experience creativity in engineering education is very useful for developing resources and comparing their interpretations to their instructors and experts. However, it would be very beneficial to understand if their attitudes have any impact on creative ability. It is recommended to design a study where the survey on attitudes towards
creativity is used in conjunction with an instrument that measures creative ability, most likely through design activities. This would enable the investigation of any correlations between attitudes and creative ability. A study of this nature has the potential to determine if it is worth investing resources to encourage students to have a more positive attitude towards engineering creativity. It may also indicate which attitudes have the largest impact on creative ability.

8.5 Implications of Inauthentic Creative Effort
The phenomenon of faking creativity was a unique finding that was not previously identified in the literature and beckons further investigation. It is a point of major concern because there is a possibility that students appear to be developing competence in creativity to their instructors, when in reality this increasingly essential engineering skill is not being developed or enhanced. This result also raises potential questions with regard to accuracy of assessment with respect to graduate attribute accreditation. If students can make it appear that they are capable of genuinely applying creative thinking in solving open-ended design problems when this is not the case, action needs to be taken.

8.6 Expansion of the Study
To increase the generalizability and validity of the findings, the study should be expanded to other Canadian universities. Collecting data from engineering students across Canada and internationally will provide a more complete understanding of students’ attitudes and experiences with engineering creativity. This will identify whether these attitudes are mutual across the country, or if they differ by region, curriculum design, program availability, or other contextual factors.
References


Appendix A

Ethics Approval Documentation

The following are the ethical approval documentation that were required to commence data collection for the study:

Figure 6: TCPS 2 - CORE Completion Certificate
August 24, 2015

Queen’s General Research and Ethics Board
Queen’s University
Fleming Hall/Jemmett Wing, 3rd floor
78 Fifth Field Company Lane
Kingston ON K7L 3N6

Dear GREB Reviewers,

I have thoroughly reviewed and support the application for Ethics Clearance for research proposed by Mr. David Waller, entitled “Exploring the Domain Specific Creativity Environment in Undergraduate Education”. This research is part of Mr. Waller’s Master’s program that is being conducted under my supervision.

Should you have any questions regarding my support for or supervision of this work, as it relates to the Ethics Board application, I would be happy to provide further information at your convenience.

Sincerely,

David Strong, P.Eng.,
Professor and NSERC Chair in Design Engineering
Appendix B

Letters of Information and Consent Forms

B.1 Letter of Information for the Survey

EXPLORING THE DOMAIN SPECIFIC CREATIVITY ENVIRONMENT IN UNDERGRADUATE ENGINEERING EDUCATION

This research is being conducted by David R. Waller under the supervision of Professor David S. Strong in the Faculty of Engineering and Applied Science at Queen’s University in Kingston, Ontario. This study has been granted clearance according to the recommended principles of Canadian ethics guidelines and Queen’s policies.

What is this study about? The purpose of this study is to explore the creativity environment in an undergraduate engineering program. The central research question is: How do students perceive the creativity environment in their engineering program? The associated sub-questions are: How do students define engineering creativity? How do students value creativity? How do students experience creativity in their engineering courses?

The study will utilize data from undergraduate engineering students. Students will be surveyed on their attitudes toward creative thinking and how they experience creativity in their engineering program. Students will be interviewed to obtain a deeper understanding of how engineering creativity is defined, how it is valued, and how it is approached in engineering education.

What will this study require? If you agree to participate in this study, your involvement will be the completion of an anonymous online survey that will take a maximum of 20 minutes to complete. The survey will ask closed and open-ended questions about the creativity environment that you experience in your engineering education. At the end of the survey, you will be asked if you are interested in participating in a voluntary follow up interview. A percentage of students who agree to follow up interviews will be selected. Students who are selected for interviews will be contacted with a new letter of information and will be required to sign a separate consent form.
Is participation voluntary? Your participation is completely voluntary and choosing not to participate will not result in any adverse consequences. There are no known physical, psychological, economic, or social risks associated with this study. You have the ability to refuse to answer any questions posed by the study. You may withdraw from the survey by closing the internet browser before submitting the survey. By closing your browser before submission, none of your responses will be recorded. There will be no negative consequences from survey withdrawal. Once the survey has been submitted, your data will not be able to be removed, but will remain anonymous.

How will my identity be protected? Survey participation will be anonymous. You will not be asked for any identifying information. Contact information will be requested if you agree to a follow up interview, but this information will only be used to contact interview participants regarding this research study and will not be associated to survey responses.

What if I have concerns? Any questions about study participation or a request to withdraw from the study may be directed to David R. Waller at david.waller@queensu.ca or my supervisor Professor David S. Strong at (613) 533-2606 or strongd@queensu.ca. Any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at (613) 533-6081 or chair.GREB@queensu.ca.

Your interest in participating in this research study is greatly appreciated. Thank you for your time and consideration.

This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen's policies.
B.2 Letter of Information for the Interview

EXPLORING THE DOMAIN SPECIFIC CREATIVITY ENVIRONMENT IN UNDERGRADUATE ENGINEERING EDUCATION

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The study will utilize data from undergraduate engineering students. Students will be surveyed on their attitudes toward creative thinking and how they experience creativity in their engineering program. Students will be interviewed to obtain a deeper understanding of how engineering creativity is defined, how it is valued, and how it is approached in engineering education.

What will this study require? If you agree to participate in this part of the study, your involvement will be a one-on-one interview that will take a maximum of 75 minutes to complete. The interview will ask open-ended questions about the creativity environment that you experience in your engineering education. Interviews will take place on your university campus at a time that is convenient for you and will be audio recorded given your permission. Interviews will follow a standard protocol and will be conducted in a semi-structured format. You will be given a $15 gift card at the end of the interview as a token of appreciation for your time. The gift card will be given upon completion of the interview. Participants who withdraw from the study prior to completion of the interview will not receive the gift card.

Is participation voluntary? Your participation is completely voluntary and choosing not to participate will not result in any adverse consequences. There are no known physical,
psychological, economic, or social risks associated with this study. You have the ability to refuse to answer any questions posed by the study. You may withdraw from the study at any time with no negative consequences. If you choose to withdraw, any interview data gathered from you will be removed from the study.

**How will my identity be protected?** Pseudonyms will be used in all publications of research data and findings. Any identifying information will be modified on interview data. All contact information will only be used for the purpose of contacting you about this research study only.

**Is there a conflict of interest?** Interview participants may be students of the interviewer (David R. Waller). To minimize this conflict of interest, a research assistant will be the only one with access to the list of volunteers. The research assistant will select interview participants from this list. The interviewer will only have access to the selected participants and will not see who has and has not agreed to participation in the interview. Participation and responses will not affect student assessment in any way.

**What if I have concerns?** Any questions about study participation or a request to withdraw from the study may be directed to David R. Waller at david.waller@queensu.ca or my supervisor Professor David S. Strong at (613) 533-2606 or strongd@queensu.ca. Any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at (613) 533-6081 or chair.GREB@queensu.ca.

Your interest in participating in this research study is greatly appreciated. Thank you for your time and consideration.

*This study has been granted clearance according to the recommended principles of Canadian ethics guidelines, and Queen's policies.*
B.3 Interview Consent Form

EXPLORING THE DOMAIN SPECIFIC CREATIVITY ENVIRONMENT IN UNDERGRADUATE ENGINEERING EDUCATION

1. I have read the Letter of Information and have had any questions answered to my satisfaction.
2. I understand that I will be participating in the study called “Exploring the Domain Specific Creativity Environment in Undergraduate Engineering Education”. I understand that the purpose of this research is to understand the creativity environment in an undergraduate engineering program by exploring perceptions of both engineering undergraduate students and engineering professors. I understand that my participation in this part of the study will entail answering open-ended questions in a one-on-one interview format and will take a maximum of 1 hour and 15 minutes.
3. I understand that my participation in this study is voluntary and I may withdraw at any time.
4. I understand that the interview will be audio recorded.
5. I understand that every effort will be made to maintain the confidentiality of the data now and in the future. Only the researcher and respective supervisor will have access to collected data. The data may also be published in professional journals or presented at scientific conferences, but any such presentations will be of general findings and will never breach individual confidentiality. In any publications or presentations, research participants will be referred to by pseudonym. Should you be interested, you are entitled to a copy of the findings.
6. I am aware that if I have any questions, concerns, or complaints, I may contact David R. Waller at david.waller@queensu.ca or my supervisor Professor David S. Strong at (613) 533-2606 or strongd@queensu.ca. Any ethical concerns about the study may be directed to the Chair of the General Research Ethics Board at (613) 533-6081 or chair.GREB@queensu.ca.

I have read the above statements and had any questions answered. I freely consent to participate in this study.

Participant’s Name (Please print): _______________________

Participant’s Signature: ______________________________

Date: ______________________________

Please retain a copy of this consent form for your records.
Appendix C

Data Collection Instruments

The following items will be asked on the survey:

<table>
<thead>
<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative people generally seem to have scrambled minds.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td></td>
</tr>
<tr>
<td>Effort in developing good creative ideas is fundamental to decision making, and as such should not be taken for granted.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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</tr>
<tr>
<td>Creative ideas seldom work out.</td>
<td>☐</td>
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</tr>
<tr>
<td>Truly creative people also have unusual lifestyles.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>During group work, the team members should encourage creative ideas by demonstrating they are willing to act on them.</td>
<td>☐</td>
<td>☐</td>
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<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I really enjoy the challenge of finding a different way to solve a problem.</td>
<td>☐</td>
<td>☐</td>
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</tr>
<tr>
<td>Really creative people are never very organized.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I don’t have much time for creativity. I’m too busy just getting my course work done.</td>
<td>☐</td>
<td>☐</td>
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<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>When I get a new idea, I really get excited.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
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<td>☐</td>
</tr>
<tr>
<td>Creativity is primarily useful for large engineering projects.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>All people have creative ideas from time to time.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>I don’t have time to be creative. I’ve got too much to do with my extra curricular</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>
commitments.
The instructors’ idea is usually the best since it comes from a much broader perspective.

Crazy sounding ideas can lead to something.

Listening to other people’s creative ideas is a waste of time.

Creativity is an important skill for engineers.

If everyone is providing ideas, no one gets any work done.

Only smart, knowledgeable people have good creative ideas.

Engineers can become significantly more creative by learning creative thinking techniques.

In my engineering course work, I find it more valuable to get the task done quickly than taking the extra time to be creative.

I feel confident being creative (applying creativity) in my engineering work (when it is expected).

←No Confidence

1 2 3 4 5 6 7 8 9 10

Complete

Confidence→

I prefer to solve the following types of engineering problems.

←Closed-ended Problems with a Correct Answer

1 2 3 4 5 6 7 8 9 10

Open-ended Problems with Many Possible Answers→
In two or three sentences, what is your definition of creativity in an engineering context?

Of the engineering courses you have taken, in what courses (if any) was creativity encouraged? If so, how was it encouraged?

In what tasks or assignments (if any) have you applied creativity in your engineering course work? If so, how?

Have you applied creativity in your extracurricular work? If so, how?

Describe the approach you take when you want to be creative in your engineering work?

What resources are available to you (if any) that help you with creativity in your engineering work?

What are barriers you experience (if any) to being creative in your engineering work?

What suggestions do you have to increase your motivation to be creative in your course work?
Select your engineering discipline.

- Chemical Engineering
- Civil Engineering
- Electrical Engineering
- Geological Engineering
- Electrical and Computing Engineering
- Engineering Chemistry
- Engineering Physics
- Mathematics and Engineering
- Mechanical and Materials Engineering
- Mining Engineering
- Undeclared

Select your year of study.

- Year 1
- Year 2
- Year 3
- Year 4
- Year 5+

Select your gender.

- Male
- Female
Appendix D

Additional Factor Analysis Results

Table 32: Initial complex structure for oblique factor analysis rotation

<table>
<thead>
<tr>
<th>Items</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only smart, knowledgeable people have good creative ideas.</td>
<td>.648</td>
<td></td>
<td></td>
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<tr>
<td>Listening to other people’s creative ideas is a waste of time</td>
<td>.495</td>
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<tr>
<td>If everyone is providing ideas, no one gets any work done.</td>
<td>.458</td>
<td></td>
<td></td>
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<tr>
<td>The instructors’ idea is usually the best since it comes from a much broader perspective</td>
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<td>Creative people generally seem to have scrambled minds.</td>
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<td></td>
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<tr>
<td>Really creative people are never very organized.</td>
<td></td>
<td>.664</td>
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<td></td>
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<tr>
<td>Truly creative people also have unusual lifestyles.</td>
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<td></td>
<td></td>
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<tr>
<td>Creative ideas seldom work out.</td>
<td></td>
<td>.329</td>
<td></td>
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<tr>
<td>I don’t have much time for creativity. I’m too busy just getting my course work done.</td>
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<td>.874</td>
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<td>I don’t have time to be creative. I’ve got too much to do with my extra curricular commitments.</td>
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<td>In my engineering course work, I find it more valuable to get the task done quickly than taking the extra time to be creative.</td>
<td></td>
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<tr>
<td>I really enjoy the challenge of finding a different way to solve a problem.</td>
<td></td>
<td></td>
<td></td>
<td>.530</td>
<td>.340</td>
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<td>Creativity is an important skill for engineers.</td>
<td></td>
<td></td>
<td></td>
<td>.530</td>
<td></td>
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<tr>
<td>During group work, the team members should encourage creative ideas by demonstrating</td>
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<td></td>
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<td>.460</td>
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<tr>
<td>When I get a new idea, I really get excited.</td>
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<td></td>
<td></td>
<td>.450</td>
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<tr>
<td>Engineers can become significantly more creative by learning creative thinking techniques.</td>
<td></td>
<td></td>
<td></td>
<td>.429</td>
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<td>Crazy sounding ideas can lead to something.</td>
<td></td>
<td></td>
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<td>.386</td>
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<td>Effort in developing good creative ideas is fundamental to decision making, and as such should not be taken for granted.</td>
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<td></td>
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<td>-.478</td>
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Figure 8: Scree plot for initial complex structure of oblique rotation factor analysis
<table>
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<th>Items</th>
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<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
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<td>Creativity is an important skill for engineers.</td>
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<td>I really enjoy the challenge of finding a different way to solve a</td>
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<td>-.344</td>
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<td>problem.</td>
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<td>During group work, the team members should encourage creative ideas</td>
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<td>by demonstrating.</td>
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<td>When I get a new idea, I really get excited.</td>
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<td>Crazy sounding ideas can lead to something.</td>
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<td>Engineers can become significantly more creative by learning</td>
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<td>-</td>
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<td>creative thinking techniques.</td>
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<td>Effort in developing good creative ideas is fundamental to decision</td>
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<td>making, and as such should not be taken for granted.</td>
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<td>my course work done.</td>
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<td>I don’t have time to be creative. I’ve got too much to do with my</td>
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<td>.718</td>
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<td>extra curricular commitments.</td>
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<td>In my engineering course work, I find it more valuable to get the</td>
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<td>.446</td>
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<td>task done quickly than taking the extra time to be creative.</td>
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<td>much broader perspective.</td>
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Figure 9: Scree plot for initial complex structure of orthogonal rotation factor analysis