ENGINEERING CREATIVITY: TOWARD AN UNDERSTANDING OF THE RELATIONSHIP
BETWEEN PERCEPTIONS AND PERFORMANCE IN ENGINEERING DESIGN

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ENGINEERING CREATIVITY: TOWARD AN UNDERSTANDING OF THE RELATIONSHIP 
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Dissertation

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ABSTRACT

Few studies have focused on perceptions of creativity in engineering. Previous researchers have tended to focus on perceptions concerning the degree to which creative thinking is emphasized in the classroom, rather than on whether students value creativity as an important part of the engineering design process. Moreover, the relationship between students’ perceptions of the importance of creative thinking in engineering design and their creative performance has not been investigated. Given the value placed on the ability of an engineer to think creatively, it is important to understand how engineering students perceive creativity as it relates to the engineering design process and whether such perceptions have the potential to influence their ability to think creatively during the engineering design process.

In this mixed-methods study, perceptions related to four primary themes: students’ perceptions of (a) the definition of creativity with respect to engineering design, (b) the importance of creativity during engineering design, (c) the extent to which creativity was developed throughout the engineering program, and (d) their own creative abilities. Themes were compared among eight engineering students who scored at the extreme ends of the Creative Engineering Design Assessment (CEDA). In addition, perceptions were gathered from 12 mechanical engineering faculty in order to compare
their perceptions of creativity in the mechanical engineering program to those of the
students.

The findings of this study support predictions made by applying the expectancy-
value theory, which holds that students who value creativity in engineering design and
confidently believe they have the ability to be creative are more likely to be creative in
various engineering design scenarios. Further, all students interviewed shared the
perception that the mechanical engineering program did little to encourage and develop
creative-thinking skills; however, students agreed the program developed the
foundational knowledge necessary for creative thought. These findings may be useful
for engineering educators as well as for guiding future researchers in the areas of
engineering education and engineering creativity.
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# TABLE OF CONTENTS

LIST OF TABLES.................................................................................................................xii

LIST OF FIGURES...................................................................................................................xiii

CHAPTER
I. INTRODUCTION.................................................................................................................. 1
   Statement of the Problem ................................................................................................. 3
   Theoretical Framework .................................................................................................... 4
   Purpose of the Study ....................................................................................................... 6
   Research Questions ......................................................................................................... 7
   Significance of the Study ................................................................................................. 8
   Limitations of the Study ................................................................................................. 10
   Definitions of Terms ....................................................................................................... 11

II. REVIEW OF THE LITERATURE ......................................................................................... 13
   Introduction ..................................................................................................................... 13
   Engineering and the Need for Creativity ....................................................................... 14
   Creativity ........................................................................................................................ 16
   A Psychological Construct without Definition .............................................................. 17
   Models of Creativity ........................................................................................................ 20
   Componential Model of Creativity .................................................................................... 21
   Chand and Runco’s Two-Tier Model of Creativity ......................................................... 24
   Systems Model of Creativity ............................................................................................ 26
   Evidence for the Domain Specificity of Creativity .......................................................... 28
   The Relationship between Creativity and Divergent Thinking ....................................... 31
The Origins and Components of Divergent Thinking.................................................. 32
Education and Creativity............................................................................................... 33
Perceptions of Creativity in Education ........................................................................ 35
Engineering Education and Creativity........................................................................ 38
The Engineering Science Model of Engineering Education ......................................... 39
Perceptions of Creativity in Engineering and Engineering Education ................. 42
The Relationship between Perception, Motivation, and Performance.................. 47
Measuring Creativity and Divergent Thinking............................................................. 50
Commonly Used Tests of Divergent Thinking and Their Psychometric Properties.......................................................... 53
Assessments to Measure Creativity and Divergent Thinking in Engineering Design.......................................................... 56
Validity of the Creative Engineering Design Assessment ......................................... 60
Reliability of the Creative Engineering Design Assessment .................................... 62
Summary ...................................................................................................................... 63

III. METHODS............................................................................................................. 65
Research Design and Philosophical Assumptions.................................................... 66
Research Questions ..................................................................................................... 68
Research Setting .......................................................................................................... 68
Participants ................................................................................................................. 69
  Senior Mechanical Engineering Students ............................................................ 70
  Mechanical Engineering Faculty ............................................................................ 70
Sampling Method ......................................................................................................... 70
  Senior Mechanical Engineering Students ............................................................ 71
  Mechanical Engineering Faculty ............................................................................ 72
Data Collection Methods and Procedures ................................................................. 73
  Creative Engineering Design Assessment ............................................................. 73
  Student Interview Protocol ...................................................................................... 74
  Faculty Questionnaire Protocol .............................................................................. 75
Procedures ................................................................................................................... 75
  Administering the CEDA......................................................................................... 77
The Selection of Interview Candidates ................................................................. 78
Mechanical Engineering Faculty Questionnaire .............................................. 79
Procedure for Training Judges to Evaluate the CEDA ................................ 80
Data Analysis ........................................................................................................ 83
Scoring of the Creative Engineering Design Assessment ............................. 83
Analysis of Creative Engineering Design Assessment Data ......................... 87
Analysis of Student Interview and Faculty Questionnaire Data ..................... 88
Data Management ................................................................................................. 92
Trustworthiness .................................................................................................... 92
Subjectivity ............................................................................................................ 93
Summary ................................................................................................................ 94

IV. FINDINGS OF THE STUDY ............................................................................ 96

Research Question 1: How creative are senior mechanical engineering students, as measured by the Creative Engineering Design Assessment? .................... 97

Research Question 2: How do perceptions of creativity in engineering design compare between senior mechanical engineering students with high and low divergent-thinking scores as measured by the Creative Engineering Design Assessment? .............................................................. 99

Selection of High-and Low-Scoring Groups .................................................... 100

Comparison of Perceptions of Creativity among High- and Low-Scoring Groups.................................................................................................................. 101

Definition of engineering design. ................................................................. 102
Definition of creativity in engineering design ................................. 102
Perceptions of the importance of creativity in engineering design 111
Perceptions of creativity in the mechanical engineering classroom. .............................. 117
Self-perception of creative abilities......................................................... 124

Research Question 3: What are the perceptions among mechanical engineering faculty of creativity in the mechanical engineering program and its development of creative-thinking skills? ............................................................................. 128

Research Question 4: How do perceptions about the mechanical engineering program and its development of creative-thinking skills compare between senior mechanical engineering students and mechanical engineering faculty? ........ 133
APPENDIX E: STUDENT INFORMED CONSENT LETTER........................................ 188
APPENDIX F: FACULTY INFORMED CONSENT LETTER...................................... 190
APPENDIX G: E-MAIL COMMUNICATION BETWEEN RESEARCHER AND INTERVIEW CANDIDATES........................................................................................................... 192
APPENDIX H: INTERNAL REVIEW BOARD NOTICE OF APPROVAL................... 193
APPENDIX I: DEMOGRAPHICS QUESTIONNAIRE.................................................. 194
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Demographic Characteristics of Student Participants (n = 42)</td>
<td>72</td>
</tr>
<tr>
<td>2. Qualifications of Judges Grading the CEDA</td>
<td>81</td>
</tr>
<tr>
<td>3. Description of Scoring Criteria for CEDA Components</td>
<td>84</td>
</tr>
<tr>
<td>4. Example Data for Showing Total CEDA Score Computation</td>
<td>87</td>
</tr>
<tr>
<td>5. A Priori Codes</td>
<td>91</td>
</tr>
<tr>
<td>6. Descriptive Statistics for CEDA Factors and Overall Score (n = 42)</td>
<td>97</td>
</tr>
<tr>
<td>7. CEDA Scores of Students Representing Extreme Scores</td>
<td>100</td>
</tr>
<tr>
<td>8. Students’ Characterization of a Creative Engineering Design</td>
<td>104</td>
</tr>
<tr>
<td>9. Students’ Characterization of Creative Individuals</td>
<td>107</td>
</tr>
<tr>
<td>10. Students’ Perceptions of Creativity as an Inborn Trait or a Developed Skill</td>
<td>109</td>
</tr>
<tr>
<td>11. Students’ Perceptions of the Importance of Creativity in Engineering Design</td>
<td>112</td>
</tr>
<tr>
<td>12. Students’ Perceptions of Creativity in the Mechanical Engineering Classroom</td>
<td>117</td>
</tr>
<tr>
<td>13. Students’ Self-Perceptions of Their Creative Abilities</td>
<td>124</td>
</tr>
<tr>
<td>14. Summary of Themes for Students’ and Faculties Perceptions of the Importance of Creativity in Engineering Design</td>
<td>133</td>
</tr>
<tr>
<td>15. Summary of Themes for Students’ and Faculties Perceptions of Creativity in the Mechanical Engineering Program</td>
<td>134</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The three components of creativity.</td>
<td>23</td>
</tr>
<tr>
<td>2. Two-tier model of creative thinking.</td>
<td>24</td>
</tr>
<tr>
<td>3. Sociocultural model of creativity.</td>
<td>28</td>
</tr>
<tr>
<td>4. Creative Engineering Design Assessment meta-cognitive processes measured</td>
<td>58</td>
</tr>
<tr>
<td>5. Creative Engineering Design Assessment processes measured.</td>
<td>59</td>
</tr>
<tr>
<td>6. Z score distribution of CEDA scores</td>
<td>88</td>
</tr>
</tbody>
</table>
CHAPTER I
INTRODUCTION

There is no doubt that creativity is the most important human resource of all. Without creativity, there would be no progress, and we would be forever repeating the same patterns.
—Edward De Bono

Engineering is inherently a creative profession. Nineteenth-century engineer Theodore Von Kármán said, “Whilst scientists study the world that is, engineers create the world that never has been” (p. 6). This statement contains the defining attribute for the engineering profession—the application of scientific principles to solve problems for which there currently are no solutions. This attribute aligns well with the commonly held definition of creativity as a process producing that which is both original and useful (Runco, 1996).

The ability to think creatively to define or solve a problem or design a novel artifact is essential to engineering as a profession, especially for future engineers (Ramaswamy, 2003). Company leaders are increasingly aware of the need for creative solutions in order to maintain a global competitive edge and respond quickly to market challenges (Baillie, 2002). Numerous reports however, have emphasized the need to help engineering students enhance their ability to think creatively during the engineering design process (Colby, Macatangay, Sheppard, & Sullivan, 2009; Felder, Rugarcia, Stice, & Woods, 2000; NAE, 2004). Given the apparent need for creative-
thinking skills, the National Academy of Engineering (NAE) has recognized creative thinking as a critical attribute deserving of increased attention within undergraduate education for practicing engineers of the future (NAE, 2004). Therefore, an important outcome for any accredited engineering program would seem to be producing graduates who are capable of creative problem-solving (Seely, 1999).

Given the value placed on creativity in engineering education (NAE, 2004), and the need for engineers who are capable of thinking creatively during the engineering design process, the question then becomes, do engineering students value creativity in engineering design? Cropley (2015) suggested,

> We can ask our students to embed creativity and innovation in their designs – we can even teach them what this means – but if students do not see the value of creativity and innovation to engineering, then our efforts may be in vain. (p. 2)

Simply put, if engineering students do not value creativity in engineering design, their motivation to be creative may be minimal, and hence they may be less likely to engage in creative thinking during engineering design.

Expectancy-value theory is the foundation for the notion that perceptions can influence one’s motivation to engage in behaviors one considers valuable (Ames, 1992; Eccles & Wigfield, 2002; Hennessey, 2002). It is important to understand the perceptions engineering students have of creativity in engineering design, as well as whether these perceptions may be influencing their creative performances. Engineering faculty and the engineering classroom environment can influence the perceptions students develop toward creativity in engineering design (Eccles et al, 1983; Eccles, 2007). Thus, this study was designed to understand the perceptions of creativity held by
students in a mechanical engineering program to provide insight into whether such
perceptions may influence their creative performance, as well as understand from the
students perspective whether the mechanical engineering program contributed toward
the development of creative-thinking skills.

Statement of the Problem

The specific problem addressed in this study was the need to understand
engineering student and faculty perceptions of creativity in engineering design, as well
as the relationship between these perceptions and creative performance. Students’
perceptions of creativity may be influenced by many factors, both internal and external
to the student, and these factors may affect the value students place upon creativity.
According to expectancy-value theory, these influences can stem from a variety of
sources, including the perceived value and emphasis engineering faculty place upon
creativity and creative thinking in the classroom, as well as internal beliefs about what it
means to be creative (Henessey, 2010; Matusovich, Miller & Streveler, 2009; Panchal et
al., 2012).

If students are expected to engage in creative thinking, it is important to
understand their views about the definition and perceived importance of creative
thinking as a component of the engineering design process. Unfortunately, students’
views about creativity in engineering design have received little attention in the
literature. Previous researchers have tended to focus on perceptions concerning the
degree to which creative thinking is emphasized in the classroom, rather than on
whether students value creativity as an important part of the engineering design
process (Daly & Tolbert, 2013). Further, both students and faculty have given contradictory statements regarding creativity in the engineering program. For example, the few researchers who have investigated this topic have concluded that students felt they were neither trained nor encouraged to be creative throughout their engineering programs (Daly & Tolbert, 2013; Daly, Mosyjowski, & Seifert, 2014; Foley & Kazerounian, 2007). However, these perceptions contrast with the findings reported by other researchers that engineering faculty feel they both value and encourage creative thinking in their students but often find it lacking in students’ work (Daly & Tolbert, 2013; Daly, Mosyjowski, & Seifert, 2014; Foley & Kazerounian, 2007).

Such conflicting views between student and faculty perceptions of the engineering classroom environment indicate a need to investigate in more depth both student and faculty perceptions of the engineering curriculum with respect to its development of creative-thinking skills. An understanding of any potential differences between students’ and faculty perceptions concerning the development of creativity in the classroom is important and has implications for students’ motivation to engage in creative thinking during the engineering design process.

**Theoretical Framework**

The premise of this study was that in order for students to be motivated to think creatively during the design process, they must believe that creative thinking is a valuable skillset for engineers to have, thereby enhancing their expectations of creative performance (Adesope, Malak, & Panchal, 2012). Thus, assessing the value and expectations students place on creative thinking in the engineering design process was
important in determining whether engineering students would be motivated to think creatively when engaged in the engineering design process.

Perception has been described in the social psychology literature as a complex construct that necessarily involves the interpretation of a confluence of internal and external stimuli and thus produces an attitudinal output based upon such interpretations (Fazio & Olsen, 2003; Lindsay & Norman, 1977; Wood, 2000). Hence, internal psychological processes, coupled with external environmental influences, cultivate perceptual mechanisms that drive creativity, or at least, the valuation of creativity and its expected outcomes. This relationship between perceptions and expected outcomes is mediated by an increase in motivation (Eccles & Wigfield, 1983, 2000). Researchers have studied outcomes of the perceptual mechanisms of both valuation and expectation with the expectancy-value theory (Eccles et al., 1983; Eccles, Schiefele, & Wigfield, 1998).

Expectancy-value theory, as a theory of motivation, has been useful in helping creativity researchers account for the various motivational reactions to environmental and personal factors that have been shown to influence creativity (Eccles et al., 1983; Eccles & Wigfield, 2000; Henessey, 2010; Matusovich, Miller, & Streveler, 2009; Panchal et al., 2012). In particular, expectancy-value theorists posit that an individual’s choice, persistence, and performance can be explained by his or her beliefs about how well he or she will do on the activity and the extent to which he or she values the activity; these beliefs are often classified as ability beliefs and value beliefs (Eccles & Wigfield, 2000). For example, people who believe an activity such as attempting to produce creative
outcomes during the engineering design process is important (value belief) and who believe they can perform this activity well (ability belief) would be more inclined to engage in creative thinking during the design process than they would be if they thought the activity was unimportant or they would not do well at it.

It is important to recognize that the interaction of both ability beliefs and value beliefs is multiplicative in nature rather than additive, as is sometimes reported in the literature (Nagengast, Marsh, Scalas, Xu, Hau & Trautwein, 2011). Therefore, the non-compensatory, multiplicative relation between ability beliefs and value beliefs indicate that both must be present and sufficiently high in order for an individual to be inclined to engage in creative thinking during the engineering design process. It is not sufficient to either enhance ability beliefs or to enhance value beliefs independent of one another; both constructs must be simultaneously enhanced for any marked affect in creative performance to occur. In other words, if a teacher emphasizes or seeks to develop one to the exclusion of the other, then the influence of each is undermined (Nagengast et al., 2011).

**Purpose of the Study**

The purpose of this study was fourfold. The first purpose was to measure the creativity of a sample of senior mechanical engineering students using an instrument called the Creative Engineering Design Assessment (CEDA). The CEDA was chosen because it allows for the measurement of students’ creative thinking skills specific to engineering design scenarios. The second purpose was to identify engineering students’
perceptions of creativity during the engineering design process and compare perceptions of students who scored at the extreme ends on the CEDA. Such comparisons fostered a better understanding of how perceptions of creativity influenced students’ creative performance outcomes. The perceptions that were investigated reflected four primary influences on motivation, in accordance with the expectancy-value theory: (a) students’ definition of creativity with respect to engineering design, (b) the importance of creativity during engineering design, (c) the extent to which creativity is developed throughout the engineering program, and (d) students’ perceptions of their own creative ability. The third purpose of this study was to gather mechanical engineering faculty perceptions of creativity in the mechanical engineering program and its development of creative-thinking skills. The fourth purpose of this study was to compare students’ perceptions of the development of creative-thinking skills throughout the mechanical engineering curriculum to the perceptions of mechanical engineering faculty to highlight similarities or differences between what students perceived and what faculty members did in the classroom.

Research Questions

This research was guided by four research questions:

1. How creative are senior mechanical engineering students, as measured by the Creative Engineering Design Assessment?

2. How do perceptions of creativity in engineering design compare between senior mechanical engineering students with high and low divergent-thinking scores as measured by the Creative Engineering Design Assessment?

   a. How do students define creativity with respect to engineering design?
b. What are students’ perceptions of the importance of creativity during engineering design?

c. What are students’ perceptions of creativity in the mechanical engineering program?

d. What are students’ perceptions of their own creative ability?

3. What are the perceptions among mechanical engineering faculty of creativity in the mechanical engineering program and its development of creative-thinking skills?

4. How do senior mechanical engineering students’ perceptions of the mechanical engineering program and its development of creative-thinking skills compare to the perceptions of mechanical engineering faculty?

**Significance of the Study**

Many researchers have focused on developing the most effective pedagogy for enhancing engineering students’ creative skills by examining the effectiveness of various learning goals, instructional methods, and assessments practices (Agogino, Dym, Eris, Frey, & Liefer, 2005; Beghetto & Kaufman, 2012; Cross & Dorst, 2001; Mishra et al., 2012). However, the effectiveness of these methods has depended on the existence of an already motivated engineering student who is simply waiting for an opportunity to be creative (Daly, Mosjowsk & Seifert, 2014; Tolbert & Daly, 2013). A prerequisite is an understanding of engineering students’ perceptions about the value of creative thinking and about the influence of such perceptions on their motivation to think creatively during design activities.

Ultimately, the significance of this study is twofold. First, the findings provide insight into the perceptions held by a sample of engineering students’ regarding creativity and the value they may place upon creativity within an engineering design.
context. Few studies have explicitly focused on engineering students’ perceptions regarding what it means to think creatively and whether the ability to think creatively is important during the engineering design process. Further, the findings could reveal possible misconceptions students have about what it means to think creatively during the engineering design process. An understanding of the value students place on creative thinking during the engineering design process is important to engineering educators considering the influence perceptions can have on a student’s motivation to think creatively (Amabile, 1993, 1996; Baer, 1998; Ermanno & Saccetti, 2013).

In addition, the findings add to our understanding concerning the relationship between perceptions of creativity in engineering design and creative performance. Although research has shown mixed perceptions regarding the value engineering students place on creativity, what is not known is whether such perceptions may be influencing students’ creative performance during engineering design activities (Foley & Kazerounian, 2007). This study was intended to fill this gap. More specifically, this study was a step toward gaining an understanding of the role creativity perceptions plays in determining whether an individual is likely to engage in creative thinking during the engineering design process. Thus, the results of this study should interest engineering educators who may be looking for ways to encourage creative thinking among their students.

Another significant aspect of this study stems from the comparison of student and faculty perceptions of creativity in the mechanical engineering program. Few studies have investigated students’ views regarding the engineering curriculum; in
particular, which aspects of the curriculum encourage creative thinking and which aspects discourage it. Comparing students’ perceptions of the engineering curriculum with the perceptions of engineering faculty may reveal an opportunity for faculty to evaluate their instructional strategies in light of students’ perceptions regarding the development of creativity in the mechanical engineering classroom.

Limitations of the Study

This study had several limitations. First, because of the purposeful nature of the selection criteria used to choose students for interviews and the resulting small sample size, the transferability of the findings to other settings may be limited. However, I have taken care to describe in detail the engineering program and the student population from which these data were collected, so that faculty and administrators of institutions of comparable size will be able to decide if the results obtained in this study are applicable to their engineering programs.

It is also important to note that the results obtained in this study were representative of the perceptions of a small sample of engineering students and faculty at a particular instant in time and thus may not reflect a stable and consistent truth, so the findings cannot be generalized to a larger population. These limitations do not lessen the importance or potential implications of this study, however. The design of this study still afforded me an opportunity to identify important themes regarding the relationship between students’ perceptions of creativity and their creative performance; they only limited the ability to generalize the findings beyond the sample of students investigated in this study.
Definitions of Terms

For the purposes of this study, the following definitions of terms were used throughout the text.

**Perceptions:** Perceptions are the interpretations of and consequently the value assigned to a particular construct which is based upon prior experiences with the construct and social interactions regarding the construct (Kaufman, 2009; Runco, 2012).

**Creativity:** Creativity is the interplay between ability and process through which an individual or group produces an outcome or product that is both novel and useful as defined within some social context (Plucker & Beghetto, 2004). This definition indicates that creativity is closely linked with divergent thinking (Plucker & Renzulli, 1999). For the purposes of this study, students’ creativity was operationally defined as the total score obtained on the creative engineering design assessment.

**Divergent thinking:** Divergent thinking is the ability to generate many alternative solutions to a given problem (Runco, 2012). Divergent thinking comprises four factors: fluency, flexibility, originality, and usefulness (Runco, 2004). For the purposes of this study, divergent thinking, as measured by the Creative Engineering Design Assessment (Charyton, 2014), was operationally defined as a measure of an individual’s creativity. It is important to note that while divergent thinking and creativity are not synonymous, it is a common practice in the literature to regard them as such because all divergent thinking tests are taken to be a measure of an individual’s creative thinking ability (Runco, 2008; Silvia, Winterstein, Willse, Barona, Cram, Hess, Martinez & Richard, 2008).
**Creative performance:** Creative performance refers to novel behavior or thinking that meets a standard of quality or utility (Armeli & Eisenberger, 1997; Guilford, 1968).

**Creative thinking:** Creative thinking involves specific thought processes that improve one’s ability to be creative, including, for example, thinking processes that allow for the generation of original, diverse, and elaborate ideas (Basadur, 1996). The term *creative thinking* is often used synonymously with divergent thinking (Runco & Acar, 2012).

**Creative self-perception/creative self-efficacy:** Creative self-perception/creative self-efficacy is a motivational state or belief that one has the knowledge and skills to produce creative outcomes (Farmer & Tierney, 2002).

**Expectancy-value theory:** Expectancy-value theory is a theory of achievement motivation used to explain and predict achievement of some goal based upon an individual’s perceptions of and hence attitudes toward that goal (Eccles et al., 1983).
CHAPERN II

REVIEW OF THE LITERATURE

The key question isn’t "what fosters creativity?" But it is why in God’s name isn’t everyone creative? Where was the human potential lost? How was it crippled? I think therefore a good question might not be why do people create? But why do people not create or innovate? We have got to abandon that sense of amazement in the face of creativity, as if it were a miracle that anybody created anything.

—Abraham Harold Maslow

Introduction

Recently, creativity has received greater attention as a necessity in engineering design (Charyton & Merrill, 2009). In describing the engineer of the future, the National Academy of Engineering (NAE; 2004) explicitly stated the need for engineers to possess practical ingenuity and creativity. The Academy further stated,

Creativity (invention, innovation, thinking outside the box, art) is an indispensable quality for engineering, and given the growing scope of the challenges ahead and the complexity and diversity of the technologies of the 21st century, creativity will grow in importance. (NAE, 2004, p. 7)

However, despite calls by the NAE that creativity is an important goal of an engineering education, several studies have indicated that creativity is rarely encouraged by faculty, and opportunities to engage in creative thinking in the classroom are often limited (Cropley, 2000, 2009; Kazerounian & Foley, 2007). This situation can alter the perceptions of creativity among engineering students. Few researchers have explored engineering students’ perceptions of creative thinking during the engineering design
process or examined how these perceptions of creativity may influence students’ creative performances.

This chapter provides a review of the creativity literature in general and then situates the literature in the context of engineering education. The chapter begins with an overview of several models of creativity that have been introduced in the creativity literature to describe the relationship between motivation and creative performance. This foundation underlies a discussion of the various frameworks researchers have used to understand the relationships among internal and external variables and their effects on creative performance, as well as the benefits and limitations of each. The relationship between creativity and divergent thinking is described. Although creativity was the primary construct of interest in this study, creativity is typically measured via divergent-thinking tests; therefore, a discussion of this relationship is included.

An overview of creativity in education and engineering education highlights the role of creativity in the classroom, as well as the various perceptions faculty have concerning its relative importance in the classroom. Additionally, the relationship between perception, motivation, and performance is reviewed in an effort to situate this study within the existing literature. Finally, I present an overview of the instruments commonly used to measure creative performance, including a psychometric evaluation of the engineering-specific divergent-thinking instrument used in this study.

**Engineering and the Need for Creativity**

Many sources, including the National Research Council (2010), have emphasized the need for a creative engineering workforce. For example, members of the President’s
Council on Jobs and Competitiveness and The Institute for the Future have noted the importance of creativity and “novel and adaptive thinking” (p. 2) as essential skills for workers of 2020.

In addition, the National Academy of Engineering (NAE, 2004) recognized creativity as a critical attribute for practicing engineers of the future, thus providing justification for focusing attention on creativity in undergraduate education. Creative problem solving will be required as the types of problems engineers encounter become more complex, driven by increasingly sophisticated technological advancements, societal and economic forces compounded by globalization, and mounting environmental concerns (Committee on Prospering in the of the 21st Century, 2007).

The NAE (2008) underscored the importance of creativity in engineering with a position statement in the report, “Changing the Conversation: Messages for Improving Public Understanding of Engineering.” The NAE indicated that to ensure the most diverse, committed base of students interested in engineering, an emphasis on creativity was essential:

No profession unleashes the spirit of innovation like engineering. From research to real-world applications, engineers constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways. Few professions turn so many ideas into so many realities. Few have such a direct and positive effect on people’s everyday lives. We are counting on engineers and their imaginations to help us meet the needs of the 21st century. (p. 10)

Creative thought processes are considered a necessity for achievement in a complex and interdependent society (Florida, 2002; Freedman, 2007). Globalization has brought an exponential rise in knowledge and technology, as well as demographic and
social changes, which have implications for engineering education and traditional STEM-related fields. For example, in the *Harvard Business Review*, Florida and Goodnight (2005) claimed a company’s most important asset was not its raw materials, transportation systems, or political influence. Instead, the most important asset was a company’s “creative capital” or “arsenal of creative thinkers whose ideas can be turned into valuable products and services” (p. 124). Further, some have even declared that the “knowledge economy” is being surpassed by the “creative economy” (Nussbaum, Berner, & Brady, 2005, para. 2). Thus, knowledge has become a commodity, and innovation and creation of new products and services is the essential new core competency for U.S. companies (Nussbaum et al., 2005).

**Creativity**

Over the past 50 years, creativity has become a highly researched area of study in the fields of psychology, education, business, and others. Much of this research has involved trying to define creativity as its own construct. Many have argued that the lack of a precise definition has restricted advances in creativity knowledge beyond what is currently known, contributing to the numerous misconceptions about the phenomenon of creativity (Kaufman, 2009; Potter, 2013; Runco & Jaeger, 2012). Despite this lack of precise definition, experts in a particular field tend to have a feel for what constitutes a creative work and what does not, and it is this generally accepted observation that allows judges, typically experts in a specific field, to impartially score creativity assessments (Hennessey, Amabile, & Mueller, 2011; Silvia, Winterstein, et al., 2008). In
the following section, I discuss some of the more commonly used definitions in the creativity literature and the perceived limitations of each.

**A Psychological Construct without Definition**

Whitman et al. (2010) stated, “creativity, occurring across a diversity of domains such as art, literature, science, mathematics, and so on, is undoubtedly influenced by a wide range of psychological and social factors, making it difficult to define in a universally acceptable manner” (p. 109). Put simply, “creativity, as has been established, is difficult to define” (Donnelly, 2004, p. 161). Many have attributed the lack of an agreed-upon definition as one of the major impediments to fruitful research in the field of creativity (Baer, 1998; Fasko, 2001; Runco & Jaeger, 2012).

Primarily because of its complex dependency upon a large number of factors, the construct of creativity is inherently difficult to define, and even meta-analyses of the construct do not include a clear definition (Kaufman & Baer, 2008). For example, Plucker et al. (2004) investigated over 90 articles from two leading journals related to the study of creativity and found that 34 (38%) researchers explicitly defined creativity. Thirty-seven (41%) offered an implicit definition, while 19 (21%) failed to offer any definition of creativity.

Often, creativity is defined in terms of the attributes possessed by creative people, products, or processes (Amabile, 1996; Csikszentmihalyi, 1996; Gardner, 1993; Taylor, 1988). Creative people typically have the ability to come up with original ideas, have different points of view beyond the status quo, and have the ability to recombine ideas or see new relationships among ideas (Amabile, 2012; Runco, 1996; Runco &
Jaeger, 2012; Torrance, 1969). Runco (2004) succinctly defined creativity as the ability to develop original ideas that are useful; this is perhaps the most widely used definition among creativity researchers, although it neglects the social boundaries with which creativity is typically identified. Csikszentmihalyi viewed creativity within a social context, defining creativity as “any act, idea, or product that changes an existing domain, or that transforms an existing domain into a new one... what counts is whether the novelty he or she produces is accepted for inclusion in the domain” (as cited in Troutmann, 2012, p. 7). Plucker, Beghetto, and Dow (2004) offered a similar but more comprehensive definition: “Creativity is the interaction between aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context” (p. 90).

In an attempt to summarize all popular definitions of creativity into one unified theory of creativity, Warr and O’Neill (2005) proposed the following definition of creativity:

Creativity is the generation of ideas, which are a combination of two or more matrices of thought, which are considered unusual or new to the mind in which the ideas arose and are appropriate to the characteristics of a desired solution defined during the problem definition and preparation stage of the creative process. (p. 122)

Although some researchers have included social, cultural, or historical dimensions in their definitions of creativity (Amabile & Tighe, 1993; Csikszentmihalyi, 1996; Gardner, 1993; Sternberg & Lubart, 1999), sometimes it is simply the Zeitgeist, or spirit of the times, that seems to set standards for labeling products as creative (Baer & Kaufman, 2008; Runco, 2004). From that perspective, creativity cannot be understood
by isolating individuals and their works from their context. Csikszentmihalyi (1996) stated, “creativity does not happen inside people’s heads, but in the interaction between a person’s thoughts and a sociocultural context. It is a systematic rather than an individual phenomenon” (p. 23).

The preceding definitions show the various ways creativity researchers have responded to the question, “What is creativity?” When answering such a question, it is important to specify what type of creativity is involved. For example, Gardner (1993) stated, “People are creative when they can solve problems, create products, or raise issues in a domain in a way that is initially novel but is eventually accepted in one or more cultural settings” (p. 116). This attribute of creative people could have been applied equally as well to either engineers or artists. This highlights the issue that, conceptually as well as practically, it is important to distinguish whether one is referring to “artistic” creativity or “scientific” creativity. Scientific creativity is the type of creativity employed by engineers during the engineering design process (Charyton, Jagacinski, Merrill, Clifton, & Dedios, 2011; Cropley & Cropley, 2000). Many creativity researchers have acknowledged that although there are many differences between scientific creativity and artistic creativity, there are almost an equal number of similarities (Baer & Kaufman, 2008; Charyton & Snelbecker, 2007; Runco, 2004, 2015).

Larson, Thomas, and Leviness (1999) attempted to describe the difference between artistic and scientific creativity by noting a seemingly obvious difference between creativity in engineering and creativity within literature, painting, and other artistic professions. Larson, Thomas, and Leviness stated, “A distinguishing feature is
that the engineer has an eye on function and utility where this is not necessarily the case with a creative sculptor, painter, poet, or musician” (p. 2). However, Weisberg (1995) noted that a common thread among both types of creativity is problem solving. The problem-solving process is common in both artistic and scientific fields; however, the nature of the problems to be solved are quite different. Thus, although the cognitive processes required for creative thinking are similar for artists and scientists, the end goal of the creative process is not.

Because of the multiplicity of factors that comprise creativity, numerous models have been developed to explain and predict creative performance. In the next section, I will discuss a few of the more noteworthy models frequently cited in the creativity literature that contribute to current understanding of creativity and the creative process.

**Models of Creativity**

Defining creativity is an important step when attempting to characterize creative people, products, and processes; understanding the factors that influence creativity is equally as important. To this end, creativity research in psychology has been conducted from different perspectives (Csikszentmihalyi, 1988; Goldenberg & Mazursky, 2000; Wolfradt & Pretz, 2001). Some researchers have focused on evaluating the creativity of products and accomplishments (Amabile, 1983; Baer, Kaufman, & Gentile, 2004; Kaufman, Baer, Cole, & Sexton, 2008; Plucker & Renzulli, 1999). Other researchers have explored the cognitive and motivational processes that lead to creative ideas (Friedman & Forster, 2001; Hirt, McDonald, & Melton, 1996; Smith, Ward, & Finke, 1995; Sternberg
& Lubart, 1999). The contextual factors that influence creative thinking and problem solving have been well studied (Forster, Friedman, & Liberman, 2004; Galinsky & Moskowitz, 2000; Maddux & Galinsky, 2009). Still other researchers have examined the relationship between individuals’ personalities and their creative performances on various tasks (Kershner & Ledger, 1985; Simonton, 2000, 2003).

In an effort to make sense of the large number of factors that influence creativity, a number of models have been developed to characterize creative behavior from a variety of different viewpoints (Amabile, 1996; Csikzentmihalyi; 2009; Runco & Chand, 1995). These models have outlined the prerequisites for and influences on the development of creativity from a variety of perspectives, including psychometric, cognitive, motivational, and sociocultural (Sternberg & Lubart, 1999). It is important to note that although these models are general in nature, they are typically applicable only to “scientific” creativity, not to “artistic” creativity, where the generalizability of most creativity models has been found to be very low (Runco, 2004).

In the following section, I describe a few of the more noteworthy models of creativity that highlight creativity from cognitive, motivational, and sociocultural perspectives. These models had particular relevance for this study because they highlight the interrelationships among various environmental factors, intrinsic motivation, and creative performance.

**Componential Model of Creativity**

According to social psychologist Amabile (1983, 1996), creativity is the confluence of three primary components: domain-relevant skills (expertise in the
domain), creativity-relevant skills (cognitive and personality processes conducive to novel thinking), and task motivation (specifically intrinsic motivation to engage in the task). The combination of these three skills is referred to as the componential model of creativity (Amabile, 1996).

Domain-relevant skills are those acquired by becoming an expert in a field, including factual knowledge, technical skills, and domain-relevant procedural skills (Amabile, 1983, 1996). Domain-relevant skills also include skills obtained through informal education, such as prior knowledge from personal experiences (Amabile, 2001). Creativity-relevant skills include seeking novelty and diversity, being independent, being persistent, and having knowledge of the heuristics involved in generating novel solutions. These skills are dependent upon one’s training, background experiences, and personality characteristics, such as self-discipline and a tolerance for ambiguity (Amabile, 2012). Intrinsic task motivation represents one’s attitude toward a task and the perceptions of one’s own motivation for undertaking the task. Intrinsic task motivation is dependent upon initial levels of intrinsic motivation toward the task as well as on the presence or absence of extrinsic motivations in the social environment.

In contrast, Eisenberger and Armeli (1997) emphasized that creativity can be fostered via external rewards (extrinsic motivation), provided that it is made clear to students what they are required to do differently or better and that they are given specific feedback based on their own behavior. This position is inconsistent with Amabile’s (1983) conclusion that extrinsic motivation is inimical to creativity (Cropley, 2000). Over the next 30 years, Amabile revised her model to include affective state as an
influence on creativity (both positive and negative), as well as extrinsic motivation, which is thought to sometimes act to enhance intrinsic motivation in what Amabile termed “motivational synergy” (Amabile, 1996). Figure 1 shows the three components of creativity.

![Figure 1. The three components of creativity.](image)

Adapted from “Sources of innovation and creativity: A summary of the research” by K. Liam, 2005, National Center on Education and the Economy. Adapted with permission.

Although Amabile’s model has been generally accepted by creativity researchers as a useful model for understanding the necessary prerequisites for creative expression, some critics have argued that Amabile’s primary interest was the motivational components of creativity. Therefore, Amabile neglected to go into any great detail concerning the nature of domain-relevant skills or how they might relate to domain-general creativity-relevant skills (Baer, 2010).
**Chand and Runco’s Two-Tier Model of Creativity**

Although Amabile’s componential model showed the prerequisite traits necessary for creativity, it did not provide detail regarding how these traits interact with each other to produce creativity. Amabile viewed these prerequisite traits as separate, noninteracting entities. Later researchers have suggested there must be congruence among all creativity relevant traits (Amabile, 2012; Runco & Chand, 1995). To fill this gap, Runco and Chand (1995) presented a model of creative thinking showing the basic components necessary for creativity and their interactions (see Figure 2). The figure contains all the essential elements of the Amabile model and in addition illustrates the complexity of creativity by showing the interactions that take place during complex creative thought.

![Figure 2. Two-tier model of creative thinking.](image)

*Figure 2. Two-tier model of creative thinking.*

The components on the bottom tier represent the controlling factors of creative thinking. Problem finding involves the cognitive components necessary for the identification and construction of problems, the selection of information, and the search for cues. Ideation represents the factors of divergent thinking: fluency, originality, and flexibility. The evaluation component represents the ability to recognize and judge the quality of creative solutions and behaviors (Runco, 1996).

The bottom tier represents the essential elements necessary for creative thinking; in contrast, the top tier contains the two necessary supporting elements for creative thinking: knowledge and motivation. In other words, knowledge, motivation, and their subcomponents are viewed as contributing rather than controlling factors that support the primary (bottom tier) factors during creative thinking. However, although this model emphasizes the interactions among cognitive elements that result in creative thinking, the model excludes the important social contexts in which creative performances are ultimately judged and accepted.

Although the two-tier model is useful in understanding the different components and interactions necessary for creative performance, like Amabile’s componential model, it is often criticized for its lack of specificity (Kaufman & Sternberg, 2010). The nature of the components and their interactions are well specified; however, the optimum levels of each component are less clear. Further, models that are designed to specify all of the components necessary for creative thinking are inherently difficult to test (Kaufman & Sternberg, 2010). Testing would require that a measurement be taken for each person for each of the components specified by the model as well as for each
complex interaction of each component. Thus, although both the componential model and the two-tier model represent useful frameworks for understanding the process of creativity, their empirical grounding is not completely clear (Lubart, 2014).

**Systems Model of Creativity**

The models discussed thus far provide frameworks for understanding creativity from a componential standpoint, in which the cognitive processes necessary for creative performance are emphasized and described. Systems approaches, however, are based on the idea that creativity cannot be identified in a vacuum, but rather comprises an interaction between the environment and the person (Starko, 2005). In general, systems theorists suggest there is interaction between cognitive, affective, motivational, and social/personal factors (Cropley, 1997). To this end, Csikszentmihaly (1988) developed a systems model of creativity that brought together all of these aspects into three primary factors: the person, the domain, and the field.

Csikszentmihalyi (1990) posited, “One finds that it is impossible to define creativity independently of judgments based on criteria that change from domain to domain and across time” (p. 198). This view implies that creativity is a social construction: Creativity can only be identified by people who share the same experiences and cultures. Hence, the environment determines the type of novelty produced and thus is an active recipient of what creative people offer (Cropley, 2001). “Creativity cannot be properly understood in isolation from the social context, for creativity is a special form of personal influence: The effective creator profoundly alters the thinking habits of other human beings” (Simonton, 1988, p. 421).
However, the emphasis on the social aspects of creativity tends to limit its usefulness as an all-encompassing model of creativity. In fact, the social focus de-emphasizes intra-psychic processes and individual contributions and instead emphasizes collaborative creativity. Thus, while the systems model has influenced many researchers (Gardner, 1993; Sawyer, 2006; Simonton, 2004) by filling an important gap in creativity research that was previously undiscussed, the model also represents an incomplete picture of creativity. Therefore, its usefulness is limited to the environmental and social aspects of creativity (Kozbelt, Beghetto, & Runco, 2010).

Despite the limitations of the systems theory of creativity, researchers have continued to use it as a model to understand how creative thinking can be guided by the social setting, becoming a reaction to the motivations of the environment (Cropley, 2001; Kaufman, 2006; Penga, Cherng, Chen, & Linc, 2013). In particular, the classroom represents an environment that can exert an influence on an individual’s creativity via the implementation of various educational activities that have been shown to encourage creative-thinking skills among students. Such activities include brainstorming exercises, open-ended design activities, open assignments and project topics that allow freedom of choice, small group discussions, journaling, and thumbnail sketches (Cole, Sugioka, & Yamagata-Lynch, 1999; Daly et al., 2014; Fleith, 2000; Houtz, 1990; Starko, 1995). In all cases, researchers have relied on subjective assessments of students’ creativity in solving the assigned problems, students’ executions of the solutions, the amount of students’ work, and the students’ written analysis of their creative processes.
These activities however, while effective in the short term, have shown limited success with respect to long-term creative performance as measured by longitudinal studies using the Torrance Tests of Creative Thinking and other similar divergent-thinking tests (Cropley & Cropley, 2000).

![Sociocultural model of creativity](image)

*Figure 3. Sociocultural model of creativity.*


**Evidence for the Domain Specificity of Creativity**

The supposition that human creativity is a generalized ability irrespective of the kind of discipline or subject matter involved has guided much of the research and theory development in the study of creativity over the last 50 years (Barron, 1988; Guilford, 1967; Hocevar, 1980; Milgram & Milgram, 1976; Plucker, 1998; Runco, 1986; Torrance, 1966, 1988). Recently however, a shift toward a domain-specific view of creativity has
been occurring in the study of creativity. Recent theoretical (Csikszentmihalyi, 1988; Gardner, 1993) and empirical (Baer, 1991, 1993) literature suggests that creativity may be a more specific trait than was once believed.

The question then becomes: is creativity a general, domain-transcending set of skills, aptitudes, traits and motivations that can be applied in any domain or are they limited to specific domains? Common usage of the word creativity suggests that most people think of creativity as a domain general skill. Creativity is seen in many ways as intelligence, a general ability that will affect performance in almost any field (Baer, 2010). More recently this perception has been challenged. Feist (2004) wrote that: “this is a rather naïve and ultimately false position and that creative talent is in fact domain specific” (p.57). Feist’s position is relatively new, but it has a growing number of supporters in the field of psychology (Baer, 2010).

The debate is primarily centered on the kind of evidence that is emphasized. Unlike proponents of domain specificity who look at creative performances, proponents of domain generality typically focus on psychometric and personality data. Plucker (1998) noted that, “The conclusions of researchers using the Consensual Assessment Technique are almost always that creativity is predominantly task or content specific, but researchers utilizing traditional psychometric methods usually conclude that creativity is predominantly domain general” (p.181). According to Baer (2010), the most likely solution to the debate is some form of hierarchical or hybrid model that takes into account both domain generality and domain specificity. Baer (2010) noted that such a model should take into consideration the following:
Talents, knowledge, skills, motivations, traits, propensities, and so forth that underlie creative performance a) vary depending on the kind of work one is undertaking b) are similar across related field or kinds of creative work, and c) become progressively dissimilar as one moves to increasingly disparate fields of endeavor. (p.338)

To this end the Amusement Park Theoretical model (Kaufman & Baer, 2004, 2005) was developed to interweave the domain-specific and domain-general approaches of creativity. According to this theoretical model, the nature of creativity has domain general skills that Kaufman and Baer call “initial requirements”, which influence creative performance in all domains (e.g., intelligence, motivation, and an appropriate environment) whereas the next level, called “general thematic areas,” is domain-specific (such as engineering or physics). They then extend the model to include domains (i.e., mechanical engineering).

Considering engineering as a broad thematic area, one can argue that specific domains of engineering would differ in the nature of the creative processes. Whereas some of the cognitive processes needed for problem solving may be common across domains of engineering (Cropley, 2015) and qualify as initial requirements, the specific strengths and weaknesses throughout the creative problem solving procedure should vary by domains (Kaufman, 2009). Differences might exist in the stages engineers undertake to tackle the same problem. Mumford, Mobley, Uhlman, Reiter-Palmon, and Doares (1991) argued that some types of creative problems presented in different domains would require greater skill in performing certain processes, and others would emphasize different processes.
Csikszentmihalyi (1999) called for empirical research examining cross-field differences in the creative process. Mumford, Antes, Caughron, Connelly, and Beeler (2010) investigated the differences in eight creative problem-solving skills across three fields (or what Kaufman and Baer might call three thematic areas): Health, Biological, and Social Sciences. Their findings suggest that these fields differ in the type of creative thinking skills they emphasize. In particular, they found that health science doctoral students performed better on problem definition, information gathering, information organization, implementation planning, and solution appraisal processes. The biological science doctoral students had stronger skills in information gathering, information organization, idea generation, and idea evaluation. The social science doctoral students had stronger conceptual combination, idea generation, and solution appraisal skills. These findings suggest that doctoral students within a particular field tend to have creative strengths in areas that are most important to their field.

The Relationship between Creativity and Divergent Thinking

It is important to understand the relationship between creativity and divergent thinking. All psychometric tests that purport to measure the processes involved in creative thinking measure divergent thinking (Kaufman & Sternberg, 2010). This is because even though creativity lacks a universally agreed-upon definition, when researchers speak of the processes involved in creative thinking, for example, the generation of ideas, as well as all the decisions, judgments, and evaluations of the ideas that follow, these are all encompassed within what creativity researchers define as divergent thinking (Runco & Jaeger, 2012).
Divergent thinking is closely related, though not synonymous, with creativity (Runco, 2008). However, divergent thinking is so fundamental to creativity, the terms divergent thinking and creativity are often used synonymously in psychology literature (McCrae, 1987; Paulus, 2000). Divergent thinking is often characterized as a measure of one’s creative potential (Runco, 2004). Strictly speaking, divergent thinking is most commonly defined as the ability to generate many alternative solutions to a given problem (Cropley, 2015; Runco, 2004, 2015).

The Origins and Components of Divergent Thinking

Guilford (1968) originally included divergent thinking as a component of a structure of intellect model. Guilford (1968) deconstructed this component into four categories necessary for the divergent production of ideas: (a) fluency, the ability to produce many ideas; (b) flexibility, the ability to produce a wide variety of ideas; (c) originality, the ability to produce novel ideas; and (d) elaboration, the ability to add value to existing ideas.

Divergent thinking is thought to occur when ideas and associations are combined, resulting in new and original ideas (Mednick, 1962; Torrance, 1995). In contrast, the goal of convergent thinking is to identify one correct or conventional answer to a given problem, for example, the type of thinking often encouraged in educational institutions. It is important to note that although they are opposites, both types of thinking are important for general problem solving because they facilitate the generation of original and effective ideas (Cropley, 2006). Hsiao and Liang (2003)
claimed that within education, both convergent and divergent thinking should be emphasized to create new ideas and ideals.

The originality of ideas produced through divergent thinking is generally considered the most distinctive attribute of creative performances (Cropley & Cropley, 2009; Runco & Acar, 2012). Basadur’s (1994) model of creative cognitive processes focused on two primary stages: ideation (divergent thinking) and evaluation (critical, convergent thinking). Although critical evaluation of ideas, actions, and decisions is an important part of the creative process, it certainly is not unique to creative processes. Critics have suggested that within the schools, students tend to be more familiar and proficient with critical evaluation than with ideation, and this proficiency is believed to interfere with creativity (Basadur, 1994; Kirton, 1976).

This situation occurs because critical evaluation is more closely associated with the type of convergent thinking often emphasized in schools, in which there is one best solution to any problem or one correct procedure for any task. This position is the opposite of ideation, which is more closely associated with creativity, that is, the ability to generate multiple potential solutions to any given problem. Thus, although convergent and divergent thinking are equally important in schools, creativity can be hampered if ideation does not take place or if critical evaluation undermines ideation processes (Amabile, 1983; Cropley & Cropley, 2009).

Education and Creativity

For over 50 years, creativity has been a major talking point, not just in engineering education, but also in education as a whole. Psychologist J. P. Guilford (as
cited in Fasko, 2001) asked, “Why is there so little apparent correlation between education and creative productiveness?” (p. 2). Referring to current “enlightened” educational practices, Guilford asked why schools were not producing more creative people (as cited in Fasko, 2001).

Many scholars have blamed a lack of opportunities to express personal creativity in the classroom as the culprit (Cooperrider, 2008; Crismond & Adams, 2012; Wilbur, 2013). For example, according to Amabile (1989), evaluation, competition, restricted choices, conformity pressure, frequent failures, and rote learning can destroy creativity in school. Torrance (1983) suggested that a misconception about young children's inability to think productively has led to an overemphasis upon recall and reproduction and a neglect of problem solving, creative thinking, and decision making in the early years. These concerns persist today.

Although many researchers have agreed that creativity is a worthwhile end in itself and is not sufficiently developed in schools, particularly in higher education, whether higher education environments are an appropriate milieu for fostering creativity in their students creativity is still a subject of debate (Fasko, 2001). This debate, however, is believed to be attributable to the myriad perceptions and misconceptions that exist within education about what exactly creativity is, what it looks like, and how to foster it (Cropley & Cropley, 2009; Kazerounian & Foley, 2007; Kim, 2011). How to foster creativity is the most difficult given the subjective nature of the construct and the lack of standardized tests to measure it (Cropley, 2000).
**Perceptions of Creativity in Education**

Many perceptions abound regarding creativity in the classroom, and many creativity researchers believe this stems from a lack of knowledge regarding how to define, identify, and foster creativity (Cropley & Cropley, 2009). Some have said such questions are the result of a lack of a precise definition of creativity, leading to poor conceptions regarding its utility to students. For example, some misconceptions about creativity include claims that creativity implies sloppiness, ambiguity, and risk taking, as well as more severe attributes such as deviance and nonconformity (Runco, 2004; Zappe et al., 2013). Although these may be the traits of some creative individuals, they do not define what it means to be creative (Zappe, Mena, & Litzinger, 2013).

Within a classroom, there may be a dichotomy between valuing creativity and holding negative perceptions toward creative behaviors and attributes. For example, a number of researchers have reported that teachers hold negative attitudes and little tolerance for behaviors and attributes associated with creativity, despite claiming they generally value it (Beghetto, 2006; Fasko, 2001; Runco, 2004; Westby & Dawson, 1995). Therefore, some teachers may follow what Alencar (2002) referred to as “inhibiting practices” (p. 5) toward the expression of students’ creativity and the realization of their creative potential. According to Alencar (2002), the term *inhibiting practices* incorporates the following: (a) emphasis on the correct response, reinforcing the fear of failure; (b) exaggerated emphasis on reproduction of knowledge; (c) low expectations about the students’ creative potential; (d) emphasis on the students’ obedience and
passivity; and (e) little emphasis on fantasy and imagination as important aspects to be taken into account (p. 5).

Westby and Dawson (1995) gave 16 elementary teachers a list of 20 items identified in the literature as being the 10 most positive and 10 most negative prototypical attributes of creative students. Some of the negative perceptions of creativity included attributes such as nonconformity, autonomy, and risk taking (Westby & Dawson, 1995). The teachers were then asked to identify which attributes belonged to their favorite students and which attributes belonged to their least favorite students (Westby & Dawson, 1995). Of the 16 teachers surveyed, only one teacher’s favorite student correlated with creative attributes ($r = .53$, $p < .02$); in all other instances, there was a negative correlation between favorite students and creative attributes, with correlations ranging from $r = -.52$ to $r = -.68$ (Westby & Dawson, 1995).

Westby and Dawson’s (1995) findings indicated that negative attitudes toward creativity can result in negative attitudes toward creative students. Citing expectancy-value theory as the motivation for his claim, Fasko (2001) suggested that negative perceptions toward creativity by teachers have the potential to influence student perceptions regarding creativity and hence the value and importance they place upon it.

Other researchers have revealed conflicts between teachers’ and researchers’ conceptions of creativity. For example, through a questionnaire administered to 49 student teachers, Diakidoy and Kanari (1999) found that 63.5% of participants believed that “creative outcomes were thought to be novel but not necessarily appropriate or correct” (p. 225). In a study by Kampylis et al. (2009), 132 in-service secondary school
teachers were administered the Teachers Conceptions of Creativity questionnaire. One out of three teachers did not believe that creativity was a key factor for personal and social progress, although 100% of all teachers in the study believed that sociocultural and environmental factors influenced creative performance in students (Kampylis et al., 2009). Given such varying perceptions about creativity, it is no wonder creativity is rarely encouraged in classrooms (Brinkman, 2010; Kampylis et al., 2009; Romero, Hyvonen, & Barbero, 2012; Teo & Waugh, 2010).

Another influence on perceptions of creativity stems from the belief that creativity is an innate quality that some students are simply born with (Fryer & Collings, 1991; O’Connor, Nemetha, & Akutsub, 2012). Although many people view creativity as a pluralized, trans-disciplinary, learnable, and teachable skill, the view that creativity is an ephemeral, nebulous trait personified in a relatively small subset of élite students is a common perception among some educators and is one reason why some teachers do not attempt to develop creativity in the classroom (McWilliam & Dawson, 2006).

Schmidt (2010) argued that such a view is dysfunctional at a societal level because there is no singularly creative archetype: Creativity correlates with a wide range of personal traits and characteristics, and its actualization is the product of a complex, dynamic interplay between personal and social factors. Psychological researchers have long supported the notion that creativity is not an innate characteristic. Evidence supports the idea that creativity and insights can be nurtured within an educational context as long as the key ingredients such as domain knowledge, motivation, and
above all, opportunities, are present (Dennard, 2000; Fichter, 2004; Kazerounian & Foley, 2007).

Not all teachers and researchers agree that creativity is something that should be, or even can be, fostered within a school setting (Fasko, 2000-2001). Creative thinking is a cognitive process that is difficult to integrate within a standardized curriculum, both at the K-12 level as well as in higher education. Some researchers have argued there are too many external influences beyond the teacher’s control (Cropley, 2000; Paris et al., 2006), and further, given the subjective nature of creative thinking and creative performance, there is as yet no standardized way of measuring creativity that is acceptable to everyone.

Researchers have shown that the classroom is an important variable for manipulating students’ perceptions of creativity as well as for enhancing or reducing their creative performance (Furman, 1998; Penga et al., 2013). Teachers can communicate information concerning the goals of a course, assignment, or project using authority, recognition, and evaluation in various learning situations, thereby influencing learners’ beliefs and consequently their motivation to achieve a particular goal or think in a particular manner (Ames, 1992).

Engineering Education and Creativity

Many of the issues that seem to hinder the inclusion of creativity development in the K-12 classroom are present in the post-secondary engineering classroom. A cursory glance of the relevant literature indicates these issues involve primarily three areas: (a) misconceptions over what creativity is and how to include it in the curriculum, (b)
varying perceptions concerning the importance of creativity in engineering practice, and (c) debates concerning whether creativity can even be taught (Dym, Agogino, Eris, Frey, & Leifer, 2005).

These issues notwithstanding, most researchers view the development of creativity as an important part of engineering education; yet, its development remains absent from the curriculum. Reasons for its absence may be found in a review of the history of engineering education in the United States, in particular, its evolution from an applied, practical discipline to an applied scientific discipline. Engineering education has gone through distinct phases throughout its history, and the nature of these phases have influenced the perception and implementation of creativity and creative thinking in engineering education. This influence is evidenced by a change in emphasis from a trial-and-error approach to a more sophisticated, scientific approach to engineering design (Kazerounian & Foley, 2007).

**The Engineering Science Model of Engineering Education**

Before engineering became a formal discipline to be studied within a structured university curriculum, engineers were artisans, craftspeople, and technical traders. Early engineering schools focused on coursework involving surveying, drafting, and basic mathematical techniques. Laboratory coursework centered on practical skills such as the operation of machine tools for both metalworking and woodworking as well as the solving of practical, industrial-type problems typically encountered on the shop floor. Hence, in the early days, engineering curricula tended to emphasize scientific
knowledge but only as it pertained to very practical industrial situations (Grayson, 1993; Michko, 2008).

Upon graduation, these early engineers typically went through an apprenticeship, consisting of on-the-job training in which an expert taught the trade to the novice apprentice. Around the turn of the 20th century, with the industrial revolution flourishing, these early engineers were found predominantly in the manufacturing sectors, focusing their skills toward solving practical problems arising on the shop floor with little regard for either scientific theory or research-related activities. At this time, most scientific engineering-related research was conducted by theoretical physicists, and the engineering designs that culminated from such research activities were often carried out by experimental physicists and chemists.

The importance of such a practical education notwithstanding, pioneers in the field of engineering struggled to earn academic credibility and professional recognition (Sheppard et al., 2009). Thus, in an effort to professionalize engineering, a stronger emphasis toward scientific theory and higher-level mathematics began to emerge in engineering curricula, although the practical components were still maintained. In the 1940s, engineering curricula tended to emphasize both pure science and practical training.

In the 1950s, Guilford’s questioning of why schools were not producing more creative people, along with concerns about national security, led to a focus on introducing creativity in the schools (Cropley, 2001; Fasko, 2001). Cropley (2001) traced the interest in promoting creative-thinking skills to the launch of Sputnik in the late
1950s. Sputnik was an artificial satellite launched by the Soviet Union to orbit Earth. This loss of the so-called “space race” was perceived as a failure of American engineering education and attributed to perceived defects in the way American engineering education was taught, leading to calls for reform (Cropley, 2000).

More emphasis needed to be placed on the basic sciences within the engineering curricula as well as on research to support scientific and technological advancement. Social critics of the day, however, argued that American schools needed to place greater emphasis on promoting creativity and original thinking, thus enabling the United States to more effectively compete in the space race against the Soviet Union (Lamancusa, Jorgensen, Zayas-Castro, & Ratner, 1995). In 1958, the United States passed the National Defense Act, an educational reform bill intended to enhance pedagogical approaches in math, science, foreign languages, and the creative arts as well as to enhance creativity and inventiveness within students (Esquivel, 1995).

This call for reform initiated what came to be known as the engineering science model of engineering education, a model that placed more emphasis on the basic sciences and mathematics within engineering curricula while de-emphasizing or in many cases abandoning all together the practical emphasis that once was the primary component of engineering curricula (Michko, 2008). Thus, in the decade between 1950 and 1960, engineering education experienced a true paradigm shift from an applied, practical focus to a mathematical, engineering science focus (Grayson, 1993).

Engineering education began to take on a new approach to educating its engineers, consisting of training in design and analysis supported by deep theoretical
knowledge of the physical sciences and higher level mathematics. Now known as the engineering science model, it originated shortly after WWII and remains virtually unchanged today. Critics of the model have argued that such an emphasis on convergent knowledge supports engineers who are capable of technical expertise but at the expense of divergent-thinking capabilities and creative output (Genco, Holtta-Otto, & Seepersad, 2012). A common criticism is that, because of such an overemphasis on analytical skills, a large number of engineering students have left college without the practical skills essential to engineers. In a review of industry leaders’ critiques concerning recent engineering graduates, a lack of creative problem-solving ability was near the top of the list (Seely, 1999).

**Perceptions of Creativity in Engineering and Engineering Education**

Engineering is a unique synthesis of mathematical and natural sciences knowledge involving skills of critical judgment and creativity, an understanding of economics, the adoption of iterative processes that embrace failure, and the desire to create technological miracles (Cho, Nijenhuis, Vianen, Kim, & Lee, 2010). In nearly every definition of engineering, creativity is included. Yet, despite the stated importance of creativity in engineering, engineers are not commonly perceived as creative professionals. In fact, a Harris Poll sponsored by the American Association of Engineering Societies and IEEE-USA found that only 3% of the respondents associated the word *creative* with engineering (Bellinger 1998; Wulf 1998).

Further, the absence of the term *creativity* or related synonyms among the Accreditation Board for Engineering and Technology (ABET) program objectives and
student outcomes indicates that, in general, engineers are not directly trained to be creative. Thus, a dichotomy seems to exist between what is implicitly valued and what is explicitly taught.

Engineering faculty members at the University of Connecticut criticized the engineering curriculum, thus illustrating some perceived disconnects between engineering education and opportunities for creative thinking:

- The typical engineering program teaches that there is a known correct answer that engineers are aiming toward and that this particular answer should be found as quickly and efficiently as possible.
- There is no room for the student to wonder, discover, and innovate.
- Curiosity, inherent in those who actually choose to be engineers, has been limited to “how something works” rather than the equally important “if something could work” in the school environment. Regurgitating known solutions has become the norm without the balance of allowing students to keep that sense of wonder.
- The majority of the engineering faculty are educated themselves in very structured programs in which scientific and mathematical accuracy was the unequivocally dominant factor. The current administrative philosophies in the schools of engineering and the evaluation, tenure, and reward systems for the engineering faculty further encourage such structured mindsets.
- Infusion of design activities in engineering curricula has been in practice mostly limited to “synthesis” exercises using known methodologies. Capstone design
projects in the senior year are valuable exercises that widen the view for engineering students. However, this stops far short of embracing and harvesting creativity as an integral part of their four-year college education in engineering. (Kazerounian & Foley, 2007, p. 11)

Despite numerous calls for more creative engineering curricula, few standard engineering courses require or even encourage creativity. This absence of opportunities to engage in creative thinking can leave students with the perception that creativity is not valued by engineering faculty or perhaps is not important in engineering as a whole (Badran, 2007; Bjorner, Kofoed, & Bruun-Pedersen, 2012; Chen & Hsu, 2006).

To encourage innovation and creative thinking among engineering students, several universities and colleges have recently implemented their own models that incorporate creativity. These models have objectives similar to the Engineer of 2020 model, in which the engineer of 2020 would possess not only strong analytical skills, but also characteristics such as practical ingenuity and creativity (NAE, 2004; Zappe et al., 2013). Stanford University, for example, has offered a course entitled “Visual Thinking” in which students’ creative-thinking skills are developed and the relationship between the engineering design process and creative thinking is investigated.

Other universities have begun integrating more design activities into their courses along with active learning methods such as cooperative learning, active learning, inductive and deductive learning, and problem- and project-based learning. At Kansas State University, the chemical engineering faculty have begun incorporating creative thinking into their senior capstone course by requiring students to design a
chemical process and then reflect on the creation process. Students answer in-depth questions aimed at developing a deep understanding of the design process. Students are required to think about the role of creativity in engineering design. In addition, the course incorporates role-playing exercises that allow students to assume the role of an engineer in real-life scenarios such as accident investigations, plant failures, or engineering design flaw investigations. Such activities are designed to facilitate opportunities to think more broadly about problems and to develop the ability to think divergently when generating solutions. Through qualitative interviews given at the end of the course, faculty have consistently found that many students enjoyed the opportunity to do something different in an engineering class. Moreover, many students stated that although they felt they had creative interests and abilities, they had not been given a chance to use them throughout the engineering program. They enjoyed the opportunity to use their creative abilities toward the solution of real-world problems (Hohn, 2010).

Similarly, Olin College has emphasized project-based learning to enhance creative problem-solving skills in several courses throughout the materials science and engineering departments. Qualitative interviews over the past several years have shown that the majority of students appreciated the open-ended nature of the projects and believed such projects allowed them more opportunities to think beyond the textbook and pull in ideas from everyday life and other courses to solve the problems effectively. However, although the feedback has been generally positive, many students stated that they did not appreciate the self-directedness of the activities, preferring a more
structured course consisting of traditional lectures, exams, and homework problems. Further, although such programs were generally considered effective at developing students’ creative thinking abilities, based on a subjective evaluation of students’ work, no quantitative evaluations were given to see if such programs had a measurable effect on students’ creative performances in other areas.

It is important to emphasize that although a few schools have intentionally integrated creativity throughout their engineering curricula, most have not. In the summers of 2011 and 2012, engineering faculty attended two workshops called “Integrating the Creative Process into Engineering Courses,” held at Pennsylvania State University. The goal of the workshops was to integrate the creative process across the engineering curricula, rather than in only design courses. Engineering faculty in attendance noted the largest barriers to facilitating creativity in the classroom included:

- Lack of time
- Need to know how to develop activities
- Student reluctance or resistance
- Difficulty with assessment
- Lack of rewards for instructor
- Lack of understanding of the creative process
- Lack of training on how to teach creative thinking (Zappe, Litzinger, & Hunter, 2012, p. 5)
Thus, pragmatic issues such as time and material constraints and a lack of knowledge about creativity in general have prohibited creativity in the engineering classroom (Schmidt, 2010). Exemplary programs such as those mentioned could act as a model for future programs when educators are trying to institute courses and activities that encourage creative thinking among engineering students.

**The Relationship between Perception, Motivation, and Performance**

The literature on individual creativity indicates that motivation is an important and necessary component for creative performance (Batey & Furnham, 2008; Collins & Amabile, 1999; Eisenberger & Shanock, 2003). Motivation typically conforms to two types: intrinsic and extrinsic. Intrinsic motivation refers to the motivation to engage in an activity for sheer pleasure or enjoyment or because the activity is valued. Extrinsic motivation, in contrast, is the motivation to do something for some external goal outside of the task itself (Hennessey, 2010).

Personality researchers frequently have included intrinsic motivation as a core characteristic of creative persons (Amabile, 2012; Penga et al., 2013; Runco, 1996). High levels of extrinsic motivation, on the other hand, have been thought to preclude high levels of intrinsic motivation; thus, as extrinsic motivators and constraints are imposed, intrinsic motivation (and creativity) would necessarily decrease. Researchers have determined that a variety of extrinsic constraints and extrinsic motivators can undermine intrinsic motivation and creativity, including expectations of reward, expected evaluation, restricted choice, an overemphasis on grades and competition,
competition, and evaluations based on normative assessments (Amabile, 1996; Hennessey, 2003; Pintrich & Schunk, 2002).

Extrinsic motivation is not completely counterproductive to creative performance. In fact, in a series of experiments, researchers found that extrinsic rewards could actually enhance intrinsic motivation and creativity when used to confirm competence, provide useful information in a supportive way, or enable people to do something that they were already intrinsically motivated to do (Amabile, 2012; Amabile & Tighe, 1993). These boosting effects were most likely to occur when initial levels of intrinsic motivation were already strong (Amabile, 2012; Amabile & Tighe, 1993).

In the creativity literature, intrinsic motivation is often viewed as a mediator between various situational influences on creativity and creative performance, with situational influences being those factors that can either constrain or enhance creativity (Runco, 2010). Amabile and Gryskiewicz (1989) and Witt and Beorkrem (1989) identified several situational influences that have been found to influence creative performance, including freedom, autonomy, good role models, resources (including time), encouragement specifically for originality, freedom from criticism, and “norms in which innovation is prized and failure not fatal” (Witt & Beorkrem, 1989, pp. 31–32).

These influences were identified in investigations conducted primarily within the field of organizational creativity, which focuses on creativity in the context of individuals working within a complex social system to create a product or service (Woodman, Sawyer, & Griffin, 1993). With respect to the classroom, it is not yet known how situational influences within the learning environment influence creative performance;
however, researchers have found that creativity tends to flourish in environments where it is valued and where this value is made explicitly known (Penga et al., 2013; Torrance, 1965, 1995).

Much of the research on classroom creativity and creative thinking involves understanding the influence of students’ beliefs, values, and goals on their intrinsic motivation and resulting creative performances. Expectancy-value theory, the theoretical framework for this study, provided a useful lens for understanding the influence perceptions of creativity can have on creative performance via intrinsic motivation. Eccles and Wigfield along with their colleagues (Eccles & Wigfield, 1995, 2002; Wigfield & Eccles, 2000, 2002), examined the relationship between expectancies and values and how they relate to children’s performance and activity choices. As a result of their analysis, the researchers developed the expectancy-value theory of motivation. The expectancy-value theory of motivation has been tested extensively in studies involving children and adolescents, particularly with regard to academic achievement (Eccles & Wigfield, 1995, 2002; Wigfield & Eccles, 2000, 2002).

In this model, expectancies represent a person’s beliefs about how well he or she will perform within a given domain, be it now or in the future. Values represent the degree of importance that an individual assigns to an activity or outcome. Specifically, it is assumed that one’s ability beliefs, one’s perceptions of task difficulty, and one’s goals and self-concept directly influence one’s expectancies and values. These expectancies and values are also influenced by the person’s perception of others’ attitudes and expectations. Thus, expectancies and values act as mechanisms in the determination of
activity choices, performance, and persistence. For example, Eccles et al. (2000) found that student’ beliefs about their abilities and their expectancies for success were the strongest predictors of subsequent grades in math, even more than the influence of previous performance in math and task achievement value. In addition, children’s task values were the strongest predictors of the intention to continue taking math and actual decisions to enroll in math courses.

Moreover, the expectancy-value model, supported by confirmatory factor analysis research (Eccles & Wigfield, 1995), suggests that expectancies and associated values are domain-specific, rather than only task specific. The results of this study suggest that the expectancy-value theory is able to make accurate predictions regarding the relationship between perceptions and performance within the domain of engineering design.

Measuring Creativity and Divergent Thinking

In the past several decades, many instruments have been created to assess creativity in a variety of formats and domains. Presently available measures of creativity can be classified into 10 categories: psychometric tools (divergent thinking tests), personality inventories, attitude and interest batteries, biographical inventories, peer nominations, teacher nominations, supervisor ratings, judgments of productions, eminence, and self-reported creative activities and achievements (Gralewski & Karwowski, 2012; Hocevar, 1981).

Researchers studying the creative aspects of individuals and their associated cognitive processes have mainly relied on the psychometric approach (Gralewski &
Karwowski, 2012). Divergent-thinking (DT) tests are considered appropriate for measuring the underlying cognitive processes involved in creative thinking (Cropley & Cropley, 2009). Most creativity tests do not measure creativity directly, but instead measure divergent thinking, a component of creativity and a reliable indicator of creative potential (Runco & Acar, 2012).

Despite the widespread use of DT tests as a measure of creativity, the tests are not without controversy. Numerous scholars doubt the validity of psychometric tests purporting to measure divergent thinking. Some have argued that divergent thinking is not equivalent to creativity (Mouchiroud & Lubart, 2001) but merely an aspect of creativity (Amabile, 1983; Runco, 1986). However, as Runco and Plucker (1998) acknowledged, rather than abandoning the psychometric method, it may be better to acknowledge its weaknesses and consider the kinds of data DT tests provide. This approach was used to assess whether measuring DT was relevant for the current study.

As some researchers have noted, the DT test is not a standardized measure of achievement or ability (Plucker & Makel, 2010); rather, it is a subjective assessment of an individual’s ability to produce original and useful ideas in response to a specific prompt. Therefore, it was important to determine what exactly is being measured with a DT test in order to discern its usefulness for this study.

Divergent thinking comprises fluency (the total number of designs), flexibility (the total number of categories the designs fit into), originality (a measure of novel, innovative, outside of the box thinking), and usefulness (the appropriateness and feasibility of the designs). Although a precise definition of creativity is still an area of
ongoing research, two crucial evaluative aspects of creativity have been highly emphasized and most widely accepted by creativity researchers, especially when the topic is real-life creativity: originality and appropriateness (Amabile, 1998; Horn & Salvendy, 2006; Paulus, 2000; Weisberg, 2006; Zeng et al., 2009b, 2010).

Empirical evidence substantiates the idea that both novelty and usefulness are indispensable in defining creativity across various domains. Some of these domains include creativity of traditional hardware products (Horn & Salvendy, 2009), information-technology products and services (Couger & Dengate, 1992; Zeng et al., 2009a, 2010), marketing strategies within the advertising industry (Kilgour, 2006), and engineered products of various types (Cropley, 2000).

Thus, it appears that creativity is often defined in terms of two socially accepted qualities that creative products and processes should have: originality and usefulness. More important, however, is that if experts agree that originality and usefulness are necessary for classifying something or someone as creative or as having a high degree of creative potential, the divergent-thinking test satisfies this criterion by virtue of its assessment of both components.

Divergent thinking is what the name implies, a cognitive process that leads to thinking in divergent directions. All DT tests, including the DT test used in this study, are designed to test an individual’s ability to engage in this type of thinking. Thus, it can be argued that whether or not divergent thinking is a component of creativity or is predictive of creativity, a divergent-thinking test contains several elements typically perceived as desirable for engineering students to have: fluent thinking, flexible...
thinking, original or “outside-the-box” thinking, and critical thinking. In other words, the skills tested in a divergent-thinking test are the most important concern for engineers and for this study, not necessarily the ill-defined construct for which it is purported to represent. Moreover, authors of DT tests do not claim DT tests measure creativity directly; this endeavor would require multifaceted, multimodal assessment methods. DT tests only measure creative potential, or more specifically, the ability to generate ideas, which is only one, albeit very important, component of creativity as defined by creativity experts (Guilford, 1968; Kaufman, 1998; Runco, 2012). To generalize the results beyond this criterion is simply misguided (Runco, 2012).

**Commonly Used Tests of Divergent Thinking and Their Psychometric Properties**

In the late 1950s through mid-1960s, Torrance developed the Torrance Test of Creative Thinking (TTCT), which has since become the most widely used instrument to assess creative potential (Lissitz & Willhoft, 1985). Its usage as an assessment tool for creative potential has also made it popular as an entrance examination for many gifted programs in school districts across the nation (Hunsaker & Callahan, 1995). The TTCT measures creative potential through the four dimensions of divergent thinking (flexibility, fluency, originality, and elaboration), as defined by Guilford (1956). The TTCT consists of open-ended activities of two types, verbal and figural. Although the TTCT-Verbal requires verbal responses, the TTCT-Figural involves responses that are visual or pictorial in nature. All activities are norm-referenced as a part of the scoring procedure. Both tests are available in pretest and posttest versions and are scored or assessed
using the manual created by Torrance. The manual provides a scoring method and includes national norms, standard scores, and national percentages for each age level.

The test manual for the TTCT shows a median interrater reliability derived from a number of studies for both the verbal and figural portions of the test, of .90 and .88, respectively. In addition, test-retest reliabilities of the four subdimensions showed a moderate reliability with values averaging .65 (Torrance, 1974a, 1974b, 2008).

Several studies using longitudinal data from Torrance’s study of elementary school students who were followed into adulthood showed that divergent-thinking ability has good predictive validity for later life creative achievements in different domains (Cramond et al., 2005; Plucker, 1999; Torrance, 1981). Torrance (1981) reported research findings from his 22-year longitudinal study in which he followed the elementary students tested from 1958 to 1964 using the Torrance Test of Creative Thinking (Torrance, 1966). Torrance’s (1981) follow-up data obtained from 1979 to 1980 showed that TTCT scores were a significant predictor of five measures of creative achievement in the postelementary school years. Further, Plucker (1999) reported in a reanalysis of Torrance’s (1969, 1983) longitudinal data that TTCT scores in the elementary school years predicted about half of the variance in adult creative achievement. Adult creative achievement was estimated through two measures: (a) an estimate of the quantity of publicly recognized achievement and (b) an estimate of the quality of creative achievement that three judges rated.

Recent research using Torrance’s longitudinal data also showed similar results. Using similar measures of creative achievement as those employed by Plucker (1999),
Cramond et al. (2005) found in a structural equation model that scores on the TTCT figural test explained 23% of the variance in creative production after 40 years. These findings indicate that divergent-thinking tests are adequate predictors of an individual’s creative potential for future problem solving (Fishkin & Johnson, 1998).

Wallach and Kogan (1965) developed an alternative to the TTCT test in 1965; the alternative test was similar to the TTCT in its inclusion of both verbal and figural divergent thinking tests. The Wallach and Kogan test used two scoring indices: fluency (number of total responses) and uniqueness (number of total responses not given by any other member of the group tested) and was presented in a game-like environment. Vosburg (1998) reported that interrater reliabilities for all subcomponents of the Wallach and Kogan test were greater than .70. Vosburg also reported an overall alpha (internal consistency) reliability of .86. To date, no longitudinal studies have been performed showing the predictive validity of this particular test.

Many other divergent-thinking tests exist, all of which are similar in structure to the original test developed by Torrance and possessing similar psychometric properties. The primary difference among them is simply the audience for whom the tests were designed. More recently, DT tests specific to the domain of engineering have been developed to assess the divergent-thinking skills of engineering students (Charyton et al., 2011; Charyton & Merrill, 2009; Shah, Millsap, Woodward, & Smith, 2012). These domain-specific DT tests are structurally the same as domain-general tests (they prompt individuals to provide as many solutions as possible to a given problem in a specific amount of time). However, in addition, the domain-specific DT tests, including the
Creative Engineering Design Assessment (CEDA), require individuals to list materials for the design, list alternative uses for the design, and list additional users of the design, in an effort to mimic the actual engineering design process.

Assessments to Measure Creativity and Divergent Thinking in Engineering Design

Creativity is generally assumed to be domain-specific (Baer, 1998; Silvia, Kaufman, & Pretz, 2009); thus, when measuring creativity within the domain of engineering, it is important to use an instrument specific to that domain. Until recently, only a few measures of creativity were available within the domain of engineering. The most common are the Owens Creativity Test (Owens, 1969) and the Purdue Creativity Test (Lawshe & Harris, 1960).

The Owens Creativity Test was developed in 1960 to assess divergent-thinking ability in the domain of mechanical engineering and to ultimately discriminate potentially creative engineers in the machine design field from those better suited for developmental work (Owens, 1969). Participants were required to list as many possible solutions as they could for various problems in machine design and other areas of mechanical engineering. The Owens Creativity Test suffered from poor reliability, however, and is no longer in print (Charyton et al., 2009).

The Purdue Creativity Test was originally developed to aid in the selection of engineers who showed the most potential for creative design and problem solving (Lawshe & Harris, 1960). Scoring is based on fluency (number of solutions generated) and flexibility (number of categories of solutions). Although the Purdue Creativity Tests
is still in use, it does not measure originality and thus is not useful as a creativity measure in the field of engineering (Charyton & Merrill, 2009).

Most recently, Charyton (2014) developed a divergent thinking test to measure an individual’s divergent-thinking capabilities within the context of actual engineering design problems. Charyton’s Creative Engineering Design Assessment (CEDA) instrument was designed to fill a need for creativity assessments specific to the domain of engineering. Specifically, Charyton’s instrument measured cognitive skills related to divergent thinking among individuals under various engineering design scenarios. Given the domain-specific nature of this inventory, it is more useful as a predictor for measuring DT ability and creative potential in engineering practice than the domain-general DT inventories previously proposed. This DT test comprises three engineering design scenarios measuring the four primary factors of divergent thinking: fluency, flexibility, originality, and usefulness. A brief description of each of the four factors that comprise divergent thinking directly measured by this test follows:

**Fluency:** Fluency is the ability to produce many ideas, operationalized by simply counting the number of ideas generated.

**Flexibility:** Flexibility refers to the ability to produce a wide variety of ideas. Operationally, it is the number of categories, types, or classifications of responses.

**Originality:** Originality is a measure of uniqueness, the ability to produce novel ideas (i.e., the ability to think outside the box). Originality is the factor most closely related to creativity.
Usefulness: Usefulness refers to the practicality of the design, based on reliability, number of purposes, and number of occasions for application.

Figure 4 shows the primary components of the creative engineering design process that provides the theoretical rationale for the test construction of the CEDA. Figure 5 shows how each item on the CEDA addresses each of the theoretical constructs shown in Figure 4.


Divergent thinking in the CEDA instrument is assessed by generating multiple solutions. Convergent thinking is assessed by solving the problem posed. Constraint satisfaction is assessed by complying with the parameters of the directions and by adding additional materials and manipulating the objects as desired. Problem finding is
assessed by identifying other uses for the design. Problem solving is assessed by deriving a novel design to solve the problem posed.

Figure 5. Creative Engineering Design Assessment processes measured.

It is worth noting that the activities contained within the CEDA were developed in such a way as to mimic the engineering design process, encompassing divergent thinking, convergent thinking, constraint satisfaction, problem finding, and problem solving (Charyton, 2011, 2014). In addition, the details comprising each step are included, namely, the initial sketching of an idea, determination of uses and materials, and the identification of other problems that may be solved with the proposed design.
Validity of the Creative Engineering Design Assessment

The validity of an instrument refers to the extent to which the items on an instrument actually measure the construct it is intended to measure (AERA, APA, & NCME, 1999). A valid instrument allows a researcher to make appropriate conclusions based upon participants’ scores on the test (Silvia, Winterstein, et al., 2008). The CEDA instrument was developed by experts in the fields of psychology and engineering; therefore, the test has content validity in terms of its appropriateness for measuring the divergent-thinking construct and its domain specificity.

Another important source of evidence needed when assessing the validity of a test such as the CEDA is how well the results of this test converge with the results of similar instruments designed to measure the same construct and discriminate against the results of instruments measuring opposite constructs. To answer this question, discriminant validity was established through the comparison of the CEDA with other general creativity measures such as the Creative Personality Scale \( r = -.007 \), the Creative Temperament Scale \( r = -.131 \), and the Cognitive Risk Tolerance Survey \( r = -.187 \); Charyton & Merrill, 2009). Traditionally, creativity researchers have concluded that an instrument is domain-specific if it is weakly correlated with an instrument purporting to be domain-general; this is sometimes known as the null effect (Silvia, Kaufman, & Pretz, 2009).

The values above were expected, given that the CEDA has the same overall structure as the aforementioned tests with the exception of additional constructs that were intended to make the test specific to the domain of engineering. Thus, although
the CEDA is not completely unrelated to other DT tests, these scores indicate there are differences, and that these differences are likely because of the domain specificity of the CEDA, rather than because of the domain generality of the other tests. Therefore, the evidence indicates that the CEDA can be considered a domain-specific and not a domain-general creativity measure (Charyton et al., 2011).

With respect to convergent validity, correlations between the CEDA and other engineering creativity and spatial measures were conducted to establish convergent validity (Charyton et al., 2011). The engineering creativity test to which the CEDA was compared was the Purdue Creativity Test (PCT), a previously validated measure rarely used today because of its lack of an originality factor within its structure. Further, the CEDA was also compared to the Purdue Visualization Spatial Test-Rotations. The CEDA was moderately correlated with the PCT ($r = 0.39, p < 0.01$) and slightly correlated with the PVST-R ($r = 0.19, p < 0.05$; Charyton, 2014). These correlations yielded similar results when the usefulness factor within the CEDA was included and excluded in the analysis. The modest correlation between the PCT and the CEDA was expected because the PCT does not include an originality section within the test, and the CEDA does. With respect to the low correlation between the PVST-R, Charyton (2011) noted that the creative engineering design as measured by the CEDA overlapped with spatial skills as measured by the PVST-R. This finding, however, was logical: Sketching requires spatial skills and participants were instructed to sketch, that is, to manipulate objects in a variety of manners in order to produce effective designs (Charyton, 2014).
Reliability of the Creative Engineering Design Assessment

Reliability refers to the consistency of the instrument and indicates that items on an instrument are consistent in representing a specific construct (AERA, APA, & NCME, 1999). With respect to tests that require a high level of judgment, assessing the reliability of an instrument can be contingent upon the reliability among independent raters; hence, the interrater reliability of an instrument becomes an important measure to be reported.

Interrater agreement establishes the equivalence of ratings obtained with an instrument when used by different raters (AERA, APA, & NCME, 1999). If a measurement process involves judgments or ratings by observers, one important measure of reliability is the consistency between raters. Interrater agreement requires completely independent ratings of the same event by more than one rater. Reliability is determined by the correlation of the scores from two or more independent raters or the coefficient of agreement of the judgments of the raters (Winterstein, 2008).

To establish the degree to which different raters agree during scoring of the CEDA, two judges were selected: one from engineering and one from psychology. Two of the CEDA test developers trained the judges. Judges practiced scoring in a team environment; however, each judge evaluated the CEDAs separately. Of the four primary factors of the CEDA, judges evaluated only the two subjective portions of the test, flexibility (categories of responses per problem) and originality (scored on an 11-point scale developed by the authors). This process occurred twice in a 5-week interval in order to establish interrater reliability through the computation of stability coefficients.
In terms of overall scoring of the CEDA, judges were in general agreement ($r = 0.98$). Interrater reliability was high for flexibility both during the initial testing and five weeks later ($r = 0.90$ and $r = 0.98$, respectively), and originality was moderately high for both initial testing and five weeks later ($r = 0.80$ and $r = 0.85$, respectively), indicating consistency in both interrater as well as test-retest reliabilities.

**Summary**

Creative thinking allows people to solve problems effectively (Mumford & Gustafson, 1988) and remain flexible (Flach, 1990) so they can cope with the advantages, opportunities, technologies, and changes of day-to-day life (Runco, 2004). Societies need new inventions, original scientific findings, and novel social programs to advance. Organizations need these elements to adapt to changing environments and succeed in the marketplace (Goldenberg & Mazursky, 2001; Goldenberg, Mazursky, & Solomon, 1999; Oldham & Cummings, 1996).

However, creativity is often a nonlinear, flexible, and messy process, encompassing ambiguity as well as failure. The problem for most engineering educators is that, although nonlinearity, messiness, ambiguity, and failure may be necessary to the process of creativity and divergent thinking, it is in stark contrast to engineering as a scientific, objective discipline, thus leading to dissonance among some engineering faculty (Kazerounian & Foley, 2007; Zappe et al., 2013).

Therefore, although ambiguity, failure, and flexibility may be important characteristics of creative people, in the realm of engineering, these terms are often equated with having low standards (Kazerounian & Foley, 2007). In the engineering
curriculum, students are expected to use well-proven techniques to solve problems or engage in design work. Such environments have the potential to alter students’ perceptions of what is valued in the engineering field, and this in turn has the potential to affect students’ actions. Whether perceptions of creativity have any influence on creative performance is an area that has not yet been investigated.

This study contributes to the understanding of creativity and the influence of perception by analyzing emerging patterns, differences, or possible misconceptions regarding how engineering students of different creative abilities perceive the notion of creativity and how these perceptions may come to influence creative performance with respect to the engineering design process.
CHAPTER III

METHODS

Creativity does not come from nowhere, but rests on a foundation of knowledge and requires effort. To be a creative engineer, you first need to be a capable, technical engineer.
—David H. Cropley

The purpose of this study was fourfold. The first purpose was to measure the creativity of a sample of senior mechanical engineering students using an instrument called the Creative Engineering Design Assessment (CEDA). The second purpose was to identify engineering students’ perceptions of creativity during the engineering design process and compare perceptions of students who scored at the extreme ends on the CEDA. Such comparisons fostered a better understanding of how perceptions of creativity influenced students’ creative performance outcomes. The third purpose of this study was to gather mechanical engineering faculty perceptions of creativity in the mechanical engineering program and its development of creative-thinking skills. The fourth purpose of this study was to compare students’ perceptions of the development of creative-thinking skills throughout the mechanical engineering curriculum to the perceptions of mechanical engineering faculty to highlight similarities or differences between what students perceived and what faculty members did in the classroom.

In this chapter I will present an overview of the research design, questions and research paradigm which guided this study, followed by the research setting, the
participants and the rationale for the selection criteria of the participants. I will then
discuss the data collection methods as well as an overview of the divergent thinking
instrument used to quantify the creative performance of the participants in this study. I
will conclude with a discussion of and means of analysis that will be used to present the
findings discussed in chapter 4 of this dissertation.

Research Design and Philosophical Assumptions

According to Newman and Benz (1998), the decision about what data to collect,
as well as what to do with the data after collection, should be dictated by the research
questions. Ridenour and Newman (2005) stated: “one can mix methods to address
different components of the same study by utilizing one method to inform the other” (p.
11). Because the purpose of this study was to collect numerical data in the form of test
scores from a creativity assessment and use this data as an input to guide the selection
of interview candidates for purposes of understanding perceptions of creativity in
engineering design, both quantitative and qualitative information would be represented
in the final database (Creswell, 2003). Hence a mixed methods approach to data
collection was employed.

Furthermore, the specific research questions and the research methods used in
this or any study presume a particular methodological perspective. Methodology, in
turn, reflects an underlying philosophy comprising an ontological view and associated
epistemological assumptions. Thus, the most fundamental consideration in posing and
answering research questions is the researcher’s philosophical or meta-theoretical
position. Ontological assumptions affect the way a researcher views the world and what
they consider to be ‘real’. Deriving from ontology is epistemology, which concerns the theory of knowledge, its nature and limits (Blackburn, 1996), and how people acquire and accept knowledge about the world. Thus researchers’ ontological viewpoints shape their epistemological beliefs in terms of how knowing and understanding reality can be developed, and of the relationships between the researcher and that which is researched.

Both the quantitative and qualitative data gathered for this study were analyzed and interpreted using a post-positivist worldview. Within this paradigm is the underlying assumption that while an absolute reality exists, such a reality can never be understood and may only be approximated (Denzin & Lincoln 2000). This differs from positivist worldview wherein a single, concrete reality is assumed to exist that we can measure, and constructivism wherein multiple realities are assumed to exist. Post-Positivism presumes that a reality does exist, but that it cannot be fully or perfectly apprehended (Guba, 1990). It is recognized that perceptions have a certain degree of plasticity (Churchland, 1979) and that there are differences between reality and people’s perceptions of reality. The concept of reality embodied within a post-positivist worldview is thus one extending beyond the self or consciousness, but which is not wholly discoverable or knowable.

Given this, post-positivism concerns itself with a probabilistic truth rather than an absolute truth, and thus seeks to understand the underlying mechanisms that drive actions and events through deductive inquiry and theory building. Furthermore, a post-positivist worldview allows for the utilization of data collection methods typically
associated with both qualitative and quantitative methodologies to aid in the processes of deduction and theory building (Healy & Perry 2000). Ultimately, this study was inherently deductive in that an overarching goal was to test the validity of expectancy-value theory in terms of its ability to predict creative performances on the basis of ability beliefs and value beliefs of senior mechanical engineering students.

**Research Questions**

This research was guided by four research questions:

1. **How creative are senior mechanical engineering students, as measured by the Creative Engineering Design Assessment?**

2. **How do perceptions of creativity in engineering design compare between senior mechanical engineering students with high and low divergent-thinking scores as measured by the Creative Engineering Design Assessment?**
   a. How do students define creativity with respect to engineering design?
   b. What are students’ perceptions of the importance of creativity during engineering design?
   c. What are students’ perceptions of creativity in the mechanical engineering program?
   d. What are students’ perceptions of their own creative ability?

3. **What are the perceptions among mechanical engineering faculty of creativity in the mechanical engineering program and its development of creative-thinking skills?**

4. **How do senior mechanical engineering students’ perceptions of the mechanical engineering program and its development of creative-thinking skills compare to the perceptions of mechanical engineering faculty?**

**Research Setting**

This research study was conducted at a large, public, urban university in the Midwest. Enrollment was 28,771 in the fall 2014 semester. At the time of this study, the
university offered over 300 baccalaureate programs, 200 master’s programs, and 37 doctoral programs.

The department, which currently has 23 tenured and tenure track faculty and seven part time faculty serves over 850 undergraduate students, making the Department of Mechanical Engineering the largest academic department in the College of Engineering at the university. The Mechanical Engineering Department maintains full accreditation with the Accreditation Board for Engineering and Technology (ABET). In alignment with the goals of the greater university in which it is housed, the department’s mission is to provide a balanced educational environment which supports both learning and research activities. The department, like the university as a whole, serves both traditional and non-traditional students, and offers both day and evening courses designed to accommodate both types of students (nontraditional students are those students who delayed post-secondary enrollment a year or more after completing high school or who attend college on a part time basis).

The gender distribution for this department is comparable to other similar sized universities offering undergraduate degrees in mechanical engineering. In particular, of the 850 undergraduate students, 76% are male and 24% are female. The ethnic distribution of undergraduate mechanical engineering students was composed of 82% Caucasian, 7.8% Asian, 5.4% African American, 2.9% Hispanic and 1.9% unknown.

Participants

This section gives an overview of the participants in this study and the rationale for their selection.
**Senior Mechanical Engineering Students.** The participants of this study included senior mechanical engineering students and faculty within the Department of Mechanical Engineering at a large Midwestern coeducational public research university. The department of mechanical engineering was chosen because it is the largest engineering department at the university and therefore provides a larger pool of students from which to choose. Senior students were purposefully chosen for this study because their perceptions were most likely to accurately reflect the importance of creativity in engineering design and the development of creative-thinking skills in the undergraduate mechanical engineering program. Moreover, the purpose behind choosing students from a single department was to maintain as much uniformity across the students as possible in terms of their courses and professors in an effort to provide as much consistency among students and their responses as possible.

**Mechanical Engineering Faculty.** All faculty in the Department of Mechanical Engineering were invited to participate in this study. Faculty were included in the study to understand their perceptions about the mechanical engineering program and its development of creative-thinking skills, as well as about any instructional methods they may have used to encourage creative thinking among students. Collecting faculty responses facilitated a comparison of student and faculty perceptions regarding creativity within the mechanical engineering program.

**Sampling Method**

In this section, I describe the sampling methods that were used to select participants for this study.
Senior Mechanical Engineering Students. Senior mechanical engineering students were selected for this study from students enrolled in the mechanical engineering laboratory course. This course was chosen because it was a required course for all senior mechanical engineering students, thus ensuring not only large enrollment numbers to widen the pool of potential participants but also providing the most diverse sample possible within the confines of the program. Although the selection of the mechanical engineering laboratory course and the class rank of the students were purposefully chosen, because of the voluntary nature of the study, the resulting number of students who chose to participate in this study constituted a convenience sample.

The mechanical engineering laboratory course consisted of both a lecture and laboratory session; the lecture was held one day per week, and the laboratory was held five days per week. Thus, 100 students attending the lecture resulted in five laboratory sessions per week, with each session holding approximately 20 students. Each student was required to attend only one laboratory session per week.

Data collection began the week of March 2, 2015, during the spring semester of classes. At the beginning of each laboratory session, I instructed the students on the goals of the study and the extent of their involvement should they choose to participate. I then requested that any student interested in participating remain in the classroom after they finished their work until all other students had completed their own labs. Each group of students took approximately one hour to complete the lab. As an incentive, refreshments were served to those students who remained in the classroom to participate in the study. After all students had completed their labs, the students
interested in participating in the study were formally instructed on the requirements for participation in the study. Of the 100 students who attended the laboratory sessions, 42 students agreed to participate in the study. Table 1 shows the demographic characteristics of the student participants.

Table 1

*Demographic Characteristics of Student Participants (n = 42)*

<table>
<thead>
<tr>
<th>Demographics</th>
<th>Frequency</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>34</td>
<td>80.00</td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>20.00</td>
</tr>
<tr>
<td>Ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>40</td>
<td>95.24</td>
</tr>
<tr>
<td>African American</td>
<td>1</td>
<td>2.38</td>
</tr>
<tr>
<td>Hispanic</td>
<td>1</td>
<td>2.38</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-24</td>
<td>42</td>
<td>100.00</td>
</tr>
<tr>
<td>Year in College</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Senior</td>
<td>42</td>
<td>100.00</td>
</tr>
</tbody>
</table>

**Mechanical Engineering Faculty.** In addition to seeking the perceptions of students, the perceptions of faculty regarding the mechanical engineering program and the extent to which it encourages creativity were also investigated. Faculty perceptions
were compared with student perceptions to highlight any differences or similarities between how students and faculty view creativity and the role of creativity during the engineering design process. The mechanical engineering faculty questionnaire, which consisted of four questions, was e-mailed to all 22 full-time faculty members in the department who had regular teaching duties (i.e., faculty who were not strictly research faculty). Of the 22 faculty members who received the e-mailed questionnaire, 12 replied.

In terms of the demographics of the 12 faculty who replied to the questionnaire, all 12 (100%) were male. With respect to race, 3 (25%) were white and 9 (75%) were Asian. The total time working as an engineering educator ranged from 2 years to 18 years for all 12 faculty members, with a mean of 10 years of service for the group. All 12 faculty taught both undergraduate and graduate level courses in the mechanical engineering program, and all faculty who completed the questionnaire had a minimum of assistant professor status or higher.

**Data Collection Methods and Procedures**

Three measures were used to collect data for this study. The three measures were the Creative Engineering Design Assessment (CEDA; see Appendix A), a student interview protocol (see Appendix B), and the mechanical engineering faculty questionnaire (see Appendix C).

**Creative Engineering Design Assessment**

Charyton developed the Creative Engineering Design Assessment (CEDA) in an effort to fill a need for creativity assessments that are domain-specific to the domain of
creativity (Silvia, Kaufman, & Pretz, 2009); the domain in this particular assessment was engineering. This particular divergent-thinking test is a recently validated inventory that provides a quantitative assessment of engineering students’ divergent-thinking ability (Charyton & Snelbecker, 2011; Charyton, 2014). A review of the psychometric properties appeared in Chapter 2.

The CEDA requires participants to sketch designs incorporating one or several three-dimensional objects, list potential users (people) of the design, and perform problem finding (generate alternative uses for their design) and problem solving in response to specific functional goals. These goals are required for each of three engineering design scenarios, and each scenario has a time limit of 10 minutes.

**Student Interview Protocol**

Interviews, as a data-collection tool, have two key strengths. First, interviews are targeted; thus, they are focused specifically on a topic, which allows expanded discussion of specific aspects of a topic. Second, interviews provide opportunities for clarification of any ideas that were unclear (Yin, 2003).

One goal of this study was to understand senior engineering students’ perceptions of creativity with respect to the engineering design process and to compare such perceptions between two student groups: those with high creative abilities and those with low creative abilities. The interview provided the means for capturing students’ perceptions of creativity and extracting relevant themes, which then facilitated a comparison of perceptions between students of high and low creativity, as measured by the CEDA.
Each interview was guided by a predetermined interview protocol consisting of 14 questions (see Appendix B). The interviews took place over the 2-week period following the collection and evaluation of all CEDA tests, from March 9 to 20, 2015. The interviews followed a semistructured protocol, chosen because it not only allowed students more freedom in their responses and the possible exploration of other related topics, but also allowed me to maintain a sense of control over the flow of the conversation (Drever, 1995).

**Faculty Questionnaire Protocol**

The 4-question questionnaire was e-mailed to all full time faculty members within the department on March 9, 2015 (see Appendix C for faculty questionnaire). In the e-mail, I asked participants to provide answers to the questionnaire with a reply e-mail. In cases for which no reply was forthcoming to the initial e-mail, after four days a follow-up e-mail was sent. When there was no reply to the second e-mail, after three days a third follow-up e-mail was sent. No further e-mails were sent to a particular faculty member if he or she had not responded after three e-mails. Twelve faculty members submitted responses to the questionnaire immediately after the first e-mail was sent out. The second and third follow-up e-mails garnered no additional faculty responses.

**Procedures**

A series of procedures were followed during the data collection portion of this study. First, after identifying the particular classroom where the laboratory course was being taught and the CEDA was to be administered, I entered the classroom and
immediately introduced myself to the teacher’s assistant (TA) in charge of the particular laboratory section. I asked for permission to introduce myself to the class and ask for volunteers willing to participate in the study (see Appendix D for participant recruitment protocol). Although permission had already been obtained from the professor on record prior to my visit, each laboratory section was taught by a TA who had heard of me via e-mail but not met me.

After permission to address the class was granted, I introduced the details of the study and subsequently asked for volunteers. I invited interested students to remain in the class after the laboratory session was over, at which time I discussed the requirements of participation in the study in more detail. Prior to the administration of the CEDA, informed consent was obtained from all students interested in participating in the study (see Appendix E). Informed consent was obtained from all faculty participants as well (see Appendix F).

After the participants signed the informed consent forms, the CEDA was administered to the students. After all the tests were completed, the three judges selected to score the tests were notified, and a convenient time was scheduled to begin scoring the tests. Before scoring of the actual tests began, all three judges were trained on how to score the CEDA in accordance with the procedures outlined later in this chapter. Both the training and subsequent scoring of the tests were done on March 7, 2015. The primary outcome of the scoring procedure was to identify the highest- and lowest-scoring students, that is, those students having the highest and the lowest creativity as measured by the CEDA. After the highest- and lowest-scoring students were
identified, these students were contacted via e-mail for individual interviews (see Appendix G for e-mail communication between researcher and interview candidates).

**Administering the CEDA**

Prior to data collection, approval from The University of Akron’s Institutional Review Board was obtained (Appendix H). As noted earlier, data collection began the week of March 2, 2015, during the spring semester of classes.

To obtain the initial creative performance data from senior mechanical engineering students, I was granted access to each of five weekly laboratory sessions for the mechanical engineering laboratory course described earlier in this chapter. As mentioned, at the beginning of each laboratory session, I informed students about the goals of the study and noted the extent of their involvement should they participate. I informed the students that their involvement would involve the completion of a divergent-thinking test as well as the possibility of being selected for follow-up interviews. I then requested that any student interested in participating remain in the classroom after they finished their labs until all other individuals had completed their own labs. The labs took approximately one hour to complete.

For students who chose to participate in the study, I handed out the informed consent letter (Appendix E), the CEDA (Appendix A), and the demographics questionnaire (Appendix I). I instructed them on how to complete the CEDA (see Appendix A for the complete opening remarks made to students as well as the instructions given for completing the test). All students who participated in the study were asked to write their student e-mail address or other frequently checked e-mail
address in the space provided on the demographics questionnaire. At this time, I assured all students who agreed to participate in the study that their identities will remain anonymous and their data will remain confidential.

The Selection of Interview Candidates

Once all the tests were evaluated and the resultant data analyzed, the interview phase of data collection began. The two groups of interest in this study represented those students who were among either the highest or the lowest scorers on the Creative Engineering Performance Assessment (CEDA) relative to all scores obtained from the tests collected. The groups representing the extreme scores were chosen for comparison in this study in order to more readily discern differences in perceptions of creativity between high- and low-scoring groups as measured by the Creative Engineering Design Assessment (CEDA). This procedure of selecting the extreme groups for analysis is consistent with the extreme-groups approach commonly used in both quantitative and qualitative research (Preacher, Rucker, MacCallum, & Nicewander, 2005).

In order to determine which students belonged in the highest and lowest creativity groups, after all students’ scores were calculated, mean score and standard deviations were calculated. Those students having the largest standard deviations, that is, students whose scores were furthest away from the mean score on both positive and negative sides were categorized as the most creative and least creative, respectively. The students who placed in the highest and lowest creativity categories were contacted for interviews using the e-mail addresses given on the demographics questionnaire.
After the students were selected, e-mails were sent (see Appendix G) to request individual semi-structured interviews. For this study, all students who were contacted replied to the initial e-mail request for an interview.

All interviews were conducted over a 2-week period from March 9 to 20, 2015, in a private room in a library at the university. This location was selected primarily because it ensured no interruption, provided a comfortable setting, and offered ease of accessibility. Because all of the students selected for interviews lived either on campus or in an apartment-type residence near campus when they were initially contacted, it was not necessary to make alternative arrangements for the interview setting.

All interviews were recorded using a digital recorder, and the digital files were subsequently stored on the same device. Interviews were also recorded on a separate recording device to ensure duplicate copies of the interviews in the event of a malfunction of the other recording device. All data obtained from the interviews were transcribed using a personal computer immediately following each interview. All interviews were transcribed verbatim.

Mechanical Engineering Faculty Questionnaire

The questionnaire used in this study contained 4 questions related to faculty perceptions of the mechanical engineering program and the extent to which they used in-class activities to encourage creative thinking (see Appendix C for faculty questionnaire). The questionnaire was e-mailed to 22 full time faculty members who had regular teaching duties in the department during March 2015.
In the e-mail, I asked participants to provide answers to the questionnaire with a reply e-mail. In cases for which no reply was forthcoming to the initial e-mail, after four days a follow-up e-mail was sent. When there was no reply to the second e-mail, after three days a third follow-up e-mail was sent. No further e-mails were sent to a particular faculty member if he or she had not responded after three e-mails. Twelve faculty members submitted responses to the questionnaire immediately after the first e-mail was sent out. The second and third follow-up e-mails garnered no additional faculty responses.

**Procedure for Training Judges to Evaluate the CEDA**

Three judges were selected to score the originality and usefulness sections of the CEDA, which were the most subjective portions of the test. The judges were selected based upon their experience and expertise in evaluating engineering designs in industrial settings. Their qualifications as judges of creative engineering designs are given in Table 2.
Table 2

Qualifications of Judges Grading the CEDA

<table>
<thead>
<tr>
<th>Judge 1</th>
<th>BS and MS in Physics, over 22 years as an engineering manager in various industries.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Judge 2</td>
<td>BS in Mechanical Engineering, MBA in Finance, over 15 years as both a design engineer and engineering manager.</td>
</tr>
<tr>
<td>Judge 3</td>
<td>BS and MS in Mechanical Engineering, over 8 years as a design engineer in various industries, accumulated over 12 patents related to various engineering designs.</td>
</tr>
</tbody>
</table>

To ensure that all three judges were evaluating the tests fairly and uniformly, I conducted a training session involving the protocol used to evaluate the tests. This training session was held immediately prior to the evaluation of the primary test data collected for this study. The practice tests used during the training session consisted of tests administered to my own students in the department of mechanical engineering technology. I began the training session by explaining the necessary steps involved in judging each test according to traditionally accepted rules governing the evaluation of divergent-thinking tests (Silvia, Winterstein, et al., 2008). Ten tests were collected for training purposes. The procedure followed by each judge consisted of four steps, described in the following paragraphs.

**Step 1: Initial overview of all tests.** Each judge began by looking through five tests to get an overview of the types of designs presented.

**Step 2: Independent evaluation of all tests by each judge.** Each judge evaluated each test independently, assigning a numerical score to the originality and usefulness
categories on the scoring sheet provided, according to the criteria listed in Table 3. This step continued until all of the tests were examined and scored by each of the three judges. It is important to note that each judge was instructed to score each test relative to the other tests only and not relative to any external criteria or standard. One of the judges asked if a particularly useful design should influence the originality score, and vice versa. I informed the judges that usefulness and originality were two separate categories and should be graded as such; in other words, scores in one category should not influence scores in any other category.

**Step 3: Determining the level of agreement between the three judges.** The criteria used to determine if each judge adequately agreed with the others aligned with the criteria described by the CEDA developer in the test manual accompanying the CEDA (Charyton, 2014). The criteria were as follows: With respect to the originality factor, if each of the three judges rated a particular design between 0 and 2, between 3 and 6, or between 7 and 10, their scores were considered in satisfactory agreement. Similarly, for the usefulness factor, if each of the three judges rated a particular design between 0 and 1, between 2 and 3, or 4, then their scores were considered in satisfactory agreement. Interestingly, the judges’ scores on both originality and usefulness did not vary by more than one point for the first five practice tests. Both the fluency and flexibility factors necessarily involved counting the total number of designs, the number of categories that each design fit within, the number of problems solved, and the number of materials used; thus, it was not necessary to determine the level of agreement on these factors.
Step 4: Reconciling differences between judges as needed. Because the level of agreement was rated satisfactory based upon the above criteria, no further training was necessary. This was the case for the first five practice tests administered to the judges. If, however, the above criteria had not been met, the judges would then have examined each other’s scores to compare scores and discuss why each judge scored the way they did. This would have allowed each judge to hone his or her scoring process and to align it with the other judges’ processes. After this step, the steps outlined above would have been repeated with the five remaining tests.

Data Analysis

The following section outlines the analysis used in scoring the data from the Creative Engineering Design Assessment and the analysis of the data collected from both the student interviews and the questionnaires completed by the faculty.

Scoring of the Creative Engineering Design Assessment

The consensual assessment technique was used to evaluate each of the tests collected during this study. The consensual assessment technique is a method of measuring creativity first proposed by Amabile (1982) and further developed by Amabile and other researchers in the last quarter century (Amabile, 1982, 1996; Baer, 1993; Baer, Kaufman, & Gentile, 2004; Hennessey, 1994). The consensual assessment technique involves the use of a panel of judges who are experts in the domain in question to evaluate the level of creativity involved in the product or process under consideration (Silvia et al., 2008; Runco, 2015). The consensual assessment technique is
a well-validated method for assessing creativity and is often referred to as the gold standard of creativity assessment techniques (Carson, 2006).

Table 3

**Description of Scoring Criteria for CEDA Components**

<table>
<thead>
<tr>
<th>Component</th>
<th>Definition</th>
<th>Score Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluency</td>
<td>This factor comprises the total number of designs, as well as the total number of descriptions, materials, and problems solved for each design.</td>
<td>A numerical score for this factor is derived by summing up the total for the following items: Total designs, Descriptions provided, Materials used, Problems solved, Users identified</td>
</tr>
<tr>
<td>Flexibility</td>
<td>This factor represents the variety or diversity of the designs. It is scored by considering how diverse the designs, descriptions, materials, problems solved and users are for each design.</td>
<td>A numerical score for this factor is derived by summing up the total of the subjective evaluation by the judges with respect to how varied and different each of the following are: Total designs, Descriptions provided, Materials used, Problems solved, Users identified</td>
</tr>
<tr>
<td>Originality</td>
<td>A measure of the unusualness or uniqueness of the designs given.</td>
<td>Designs are assigned a numerical score based on the following scale:</td>
</tr>
<tr>
<td>Usefulness</td>
<td>A measure of the applicability and practicality of the design to the problem being solved.</td>
<td>Designs are assigned a numerical score based on the following scale:</td>
</tr>
</tbody>
</table>
Three engineering design scenarios were completed by each student, with a time limit of 10 minutes per scenario. The judges used a scoring sheet to assess each student’s test with respect to the four factors that comprise divergent thinking: fluency, flexibility, originality, and usefulness. The scoring criteria for each of the four factors were derived from the CEDA user’s manual (Charyton, 2014; see Table 3).

In terms of the actual scoring process itself (i.e., assigning a numerical score to each design for each individual factor), the judges were instructed to use their expert sense of what is original and useful in order to rate each of the designs in relation to one another. That is, the judges were told they should compare each design only to the pool of designs being judged at that instant; this was the motivation for having each judge skim over each test before official scoring began in order to get a feel for the level of creativity within the pile of tests.

Thus, high or low levels of creativity, as revealed by the numerical scores assigned by each judge, referred to differences within the group of designs being judged at that particular time, not in comparison to any external standard. The goal was to obtain ratings that reflected the comparative creativity of all the designs being judged.

For example, imagine four students were administered the CEDA, and after the judging process, they each were given certain scores in each of the four categories that comprise the CEDA. Table 4 shows an example of this scenario. The scores for fluency, flexibility, originality, and usefulness for each of the three design problems were determined using the criteria described in Table 3. The scores listed in Table 4 for each factor represent the total cumulative score on each factor for all three design problems.
that comprise the CEDA. The total score was then obtained by inputting the score for each factor into the following equation and computing a total score:

Total CEDA score = cumulative fluency score + cumulative flexibility score + (cumulative originality score \times 2) + (cumulative usefulness score \times 2)

For example, inputting the scores obtained by Student A into the equation results in the following:

Total CEDA Score = 9 + 10 + (10.3 \times 2) + (8 \times 2) = 55.6

Once a particular test had been evaluated and assigned a total score by each of the three judges, a final numerical score for each test was then assigned by averaging each of the three final scores given by each judge. Based on the total distribution of scores obtained from all students taking the test, the highest and lowest scorers were selected for the high- and low-scoring groups by determining which scores were the furthest away from the total mean score, both above and below the mean.
Table 4

*Example Data for Showing Total CEDA Score Computation*

<table>
<thead>
<tr>
<th>Student</th>
<th>Cumulative Fluency</th>
<th>Cumulative Flexibility</th>
<th>Cumulative Originality*†</th>
<th>Cumulative Usefulness*†</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>9</td>
<td>10</td>
<td>10.3</td>
<td>8</td>
<td>55.6</td>
</tr>
<tr>
<td>B</td>
<td>26</td>
<td>19</td>
<td>22.15</td>
<td>12</td>
<td>113.3</td>
</tr>
<tr>
<td>C</td>
<td>35</td>
<td>30</td>
<td>27</td>
<td>13</td>
<td>145.0</td>
</tr>
<tr>
<td>D</td>
<td>19</td>
<td>5</td>
<td>5</td>
<td>6.4</td>
<td>46.8</td>
</tr>
</tbody>
</table>

* Originality and usefulness scores multiplied by 2.
† Cumulative originality and cumulative usefulness scores represent the average of three judges’ scores.

**Analysis of Creative Engineering Design Assessment Data**

One of the primary goals of this study was to understand how perceptions of creativity in engineering design compare between senior mechanical engineering students with high and low creativity scores, as measured by the Creative Engineering Design Assessment. In order to find which students would be placed into the high- and low-scoring groups, mean score and standard deviations were calculated based on the total scores obtained for the students. Students with the largest standard deviations (i.e., students whose scores were furthest away from the mean score) were categorized as the most creative and least creative, respectively.

To simplify the categorization, student’s total scores were converted to z scores (i.e., scores were converted to standard deviation units such as ±1σ, ±2σ, etc., with σ
being the symbol for standard deviation). Z scores were chosen as the criterion for determining which students had the highest and lowest scores because it measures how much a score deviates from the mean in both positive and negative directions, and thus readily shows how well a student did in comparison to every other student. This calculation method facilitated grouping of students into highest and lowest creativity categories.

Those students whose scores fell into the range that deviated the most from the mean score were selected for interviews. The frequency of scores with respect to z-score groupings are shown in Figure 6.

![Z Score Distribution of CEDA Scores](image)

**Figure 6.** Z score distribution of CEDA scores

**Analysis of Student Interview and Faculty Questionnaire Data**

Data analysis of the student interview data occurred in two phases: within-group analysis and across-group analysis. In other words, students’ perceptions were coded
and emergent themes synthesized within each group of high- and low-scoring students first, and then themes emerging from each group were compared across the high-scoring and low-scoring groups.

Data analysis began with the generation of codes that emerged from the responses of each individual student interviewed. The responses for each student were coded individually before assigning the student to a high- or low-scoring group, thus expediting a relatively nonbiased coding process. This process ensured the codes were reflective of the responses themselves rather than of the particular group to which they were assigned. An *a priori* code list based on themes found in the literature was used as a guide during the initial coding process, shown in Table 5. After codes were generated for each student, students were categorized according to which creativity group they belonged, and within each group, themes were developed and synthesized based upon the codes generated from each group member’s responses. In other words, codes were analyzed and resultant themes were synthesized in a manner reflective of each group’s overall perceptions.

This process was performed for each of the four major categories of questions in this study: (a) students’ definitions of creativity with respect to engineering design, (b) perceptions of the importance of creativity during the engineering design process, (c) perceptions of their own creative self-efficacy, and (d) perceptions regarding the value they felt engineering faculty placed on creative thinking and the degree to which they felt creative thinking was encouraged in the engineering classroom.
The primary purpose of this research was to compare the perceptions of creativity between high- and low-scoring students; thus, a cross-group analysis was performed to identify similarities or differences among themes emerging from each group in terms of the four major categories mentioned. This analysis forms the basis of the findings discussed in Chapter IV.

The data emerging from the mechanical engineering faculty questionnaire were analyzed in the same manner used to analyze the student interview responses. Codes were generated and resultant themes were developed that were reflective of the perceptions of mechanical engineering faculty with respect to the four questions asked on the questionnaire. Such themes were synthesized in a manner reflective of the entire group, and such themes were then compared to students’ themes to identify similarities or differences between students’ and faculty’s perceptions of creativity in engineering design.
### A Priori Codes

<table>
<thead>
<tr>
<th>Coding Categories</th>
<th>Definition</th>
<th>A Priori Codes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definitions of creativity</td>
<td>Student’s definition of creativity and what it means to think creatively with respect to the engineering design process.</td>
<td>Useful, realistic, unique, novel, original, socially dependent acceptability, outside of the box</td>
</tr>
<tr>
<td>Importance of creativity during engineering design</td>
<td>Student’s perception of the importance of being able to think creatively and produce creative outcomes during the engineering design process.</td>
<td>Extends scientific progress, allows for technological advancement, mold breaking, non-scientific, wastes time, unnecessary risk taking, playing around</td>
</tr>
<tr>
<td>Development of creative-thinking skills in engineering program</td>
<td>Student’s perception of the mechanical engineering program and the degree with which creativity is developed and/or emphasized throughout</td>
<td>Open-ended problem solving, closed-ended problem solving, experimentation, flexibility, originality, multiple solutions, one correct solution, convergent thinking</td>
</tr>
<tr>
<td>Self-perceptions of creative abilities</td>
<td>Student’s perception that he/she has the knowledge and skills to produce creative outcomes (Tierney &amp; Farmer, 2002)</td>
<td>Confidence in abilities, I have always been creative, others always tell me I’m creative, I enjoy being creative, I enjoy solving problems, sense of excitement when being creative.</td>
</tr>
</tbody>
</table>
Data Management

Each interview was transcribed within a week of the interview. Each transcribed interview was assigned page numbers, line numbers and pseudonyms were added to protect the identity of each participant. This established an audit trail which helped contribute to the reliability of the study. The following nomenclature was used following all interview transcript references and appears immediately following all such references. For example, 1Harold.2.3 would indicate the quote came from the first interview with Harold, with the quote appearing on page two, line number 3 of the transcript.

To maintain confidentiality, all hard copy data was stored in a locked filing cabinet and all electronic files were stored on a password protected computer to which only I have access. In addition, all electronic files were backed up on a password protected network.

Trustworthiness

Trustworthiness in qualitative research refers to the credibility, transferability, dependability, and confirmability of the study (Lincoln & Guba, 1985). To this end, I was cognizant of ensuring the data collection and analysis processes were as transparent as possible, thereby ensuring later researchers could replicate this study. This was accomplished by providing a clear description of the data collection procedures and interview protocols. This clarity and detail added dependability, or reliability, to the study (Gall, Gall, & Borg, 2005; Yin, 2009).
Moreover, the methods involved in the qualitative inquiry portion of this study were applied with consistency and neutrality, thereby ensuring the likelihood that the perceptions uncovered in this study was genuinely a reflection of the students’ perceptions at time the interviews were conducted. This consistency and neutrality enhances the transferability of the study’s findings (Lincoln & Guba, 1985). Moreover, multiple data sources were employed, including both engineering student interviews and engineering faculty questionnaire. Finally, as I collected the data I carefully coded each item and created an audit trail. Details related to the validity and reliability of the instrument (CEDA) used to collect quantitative data for this study was described in detail in chapter 2.

Subjectivity

Having gone through the same engineering program that I was interviewing students about, I was aware that I held certain beliefs and predispositions regarding the program I was inquiring about. In other words, while students shared their perceptions regarding the mechanical engineering program and the degree with which they believed it developed their creativity, I also had my own perceptions to this line of questioning. These perceptions could have a tendency to muddy my interpretation of the responses given. Furthermore, unlike most qualitative inquiries in which there typically exists no right or wrong answer per se, for this study, some of the questions asked did have an agreed upon “right” answer according to the literature. Such a preexisting knowledge of what the right answer should be can potentially bias the lens through which I viewed the given responses. Moreover, my theoretical framework was such that it made
predictions about students perceptions based upon their creative performance on the CEDA. This had the potential to influence my perceptions of the responses given by the students.

In addition, any study such as this must necessarily operationally define the construct in question in order to accurately interpret the perceptions espoused by the participants of this study. As stated in the definition of terms section in chapter one, creativity was operationally defined as the total score obtained by students’ on the CEDA. This admittedly narrow view of creativity, while necessary for the extraction and interpretation of relevant themes from the interview data, likely narrowed the lens with which I interpreted the responses from each of the participants, and therefore any examination of the conclusions drawn in this study must be vetted in light of this admission.

It is only by exposing ones potential bias that a researcher can actively work to minimize them. With that in mind, I read through my findings multiple times and questioned my conclusions at every turn, thus ensuring that any conclusions drawn were based upon what students actually said, and not a result of me filling in the blanks for the students when responses seemed vague.

**Summary**

In this chapter, a rationale for a mixed methods study was provided along with a discussion of the philosophical underpinnings which guided this study. A discussion regarding the design of the study and a description of the participants of the study was given. A description of the type of data that was collected from all of the participants,
the methods used to collect the data, and the manner in which it was analyzed was also given. Finally, the limitations inherent in the study were discussed as well as issues of trustworthiness and subjectivity and how measures were taken to address such issues.
CHAPTER IV

FINDINGS OF THE STUDY

*Creativity can solve almost any problem. The creative act, the defeat of habit by originality, overcomes everything.*
—George Lois

The purpose of this study was fourfold. The first purpose was to measure the creativity of a sample of senior mechanical engineering students using the Creative Engineering Design Assessment (CEDA) instrument. The second purpose was to identify engineering students’ perceptions of creativity during the engineering design process and compare perceptions of students who scored at the extreme ends on the CEDA. Such comparisons fostered a better understanding of how perceptions of creativity influenced students’ creative performance outcomes. The third purpose of this study was to gather mechanical engineering faculty perceptions of creativity in the mechanical engineering program and its development of creative-thinking skills. The fourth purpose of this study was to compare students’ perceptions of the development of creative-thinking skills throughout the mechanical engineering curriculum to the perceptions of mechanical engineering faculty to highlight similarities or differences between what students perceived and what faculty members did in the classroom.

This chapter is divided into four sections, organized by research question. In the first section, I describe the results of the Creative Engineering Design Assessment (CEDA)
and the selection of the high- and low-scoring groups to answer the first research question. The second section provides a synthesis of the perceptions of creativity in engineering design of students who were assigned to the high- and low-scoring groups to answer the second research question. In response to the third research question, I review faculty perceptions of creativity in the mechanical engineering program. Finally, to answer the fourth research question, I compare faculty perceptions to those of the students from within both the high- and low-scoring groups.

**Research Question 1: How creative are senior mechanical engineering students, as measured by the Creative Engineering Design Assessment?**

Research Question 1 addressed the creative performance of 42 senior mechanical engineering students as measured by the Creative Engineering Design Assessment (CEDA). The mean, standard deviation, minimum, and maximum scores are presented for each of the four factors and for the students’ overall CEDA score. The descriptive statistics are presented in Table 6.

Table 6

*Descriptive Statistics for CEDA Factors and Overall Score (n = 42)*

<table>
<thead>
<tr>
<th>Factor</th>
<th>n</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Mean</th>
<th>SD</th>
<th>Skewness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluency</td>
<td>42</td>
<td>7</td>
<td>60</td>
<td>32.59</td>
<td>11.83</td>
<td>0.019</td>
</tr>
<tr>
<td>Flexibility</td>
<td>42</td>
<td>5</td>
<td>49</td>
<td>20.86</td>
<td>11.13</td>
<td>1.087</td>
</tr>
<tr>
<td>Originality</td>
<td>42</td>
<td>6</td>
<td>29</td>
<td>12.81</td>
<td>5.96</td>
<td>1.261</td>
</tr>
<tr>
<td>Usefulness</td>
<td>42</td>
<td>4</td>
<td>24</td>
<td>10.60</td>
<td>4.87</td>
<td>1.120</td>
</tr>
<tr>
<td>Total Score</td>
<td>42</td>
<td>42</td>
<td>207</td>
<td>100.26</td>
<td>39.37</td>
<td>1.356</td>
</tr>
</tbody>
</table>
The fluency factor is a count of the number of responses given by the student to each design problem. Fluency is central to divergent thinking because it measures the speed at which students generate solutions to a problem. The maximum score of 60 and minimum score of 7 indicate a large range in terms of fluency scores among students who completed the CEDA. However, the skewness value of .019, which falls within the acceptable range for normality of between −1 and +1, shows a relatively normal distribution of fluency scores with the majority of values concentrated about the mean fluency score of 32.59.

Flexibility refers to the number of types or categories found in the responses for each problem, representing a measure of the variety or diversity of responses given for each problem. Similar to fluency, the flexibility factor shows a large range in scores, with a maximum score of 49 and minimum score of 5. This large range is indicative of a large variation in the abilities of these students to come up with diverse solutions to the given design problems. Moreover, the skewness value of 1.087 for flexibility shows a positively skewed distribution of flexibility scores, indicating the majority of scores for flexibility were less than the mean score of 20.86.

Originality is an indicator of a student’s ability to come up with solutions that are considered novel and was assessed based on a rubric consisting of descriptors and numbers on a scale from 0 to 10 (see Table 3). The maximum score of 29 and minimum score of 6 indicates a large range of originality scores among students. The skewness value of 1.261 for originality shows a positively skewed distribution of scores, indicating the majority of scores for originality were less than the mean score of 12.81.
Usefulness is a measure of the practicality of the design for current or future uses, measured on a scale that ranged from 0 to 4 (see Table 3). The maximum score of 24 and minimum score of 4 indicates a large range of usefulness scores among students. The skewness value of 1.120 for usefulness shows a positively skewed distribution of scores, indicating the majority of scores for usefulness were less than the mean score of 10.60.

In all, the wide range in total scores, ranging from a low of 42 to a high of 207, is representative of the trend seen in scores on each of the sub-factors, showing that a wide variation in creative performances exists among the 42 senior mechanical engineering students tested for this study. Moreover, a skewness value of 1.356 for the total CEDA score shows a positively skewed distribution, indicating the majority of total scores on the CEDA were less than the mean score of 100.26.

**Research Question 2: How do perceptions of creativity in engineering design compare between senior mechanical engineering students with high and low divergent-thinking scores as measured by the Creative Engineering Design Assessment?**

This section includes a description of the procedure used for selecting the students for the high- and low-scoring groups based on the quantitative data collected from the CEDA. A comparison of the qualitative data collected for this study about the perceptions of creativity of students placed in the high- and low-scoring groups is also presented.
Selection of High-and Low-Scoring Groups

From the distribution of students overall scores on the CEDA, four students scored greater than or equal to 3 standard deviations above the mean score of 100.26. In addition, four students scored less than or equal to 2 standard deviations below the mean. In accordance with the objective of Research Question 2, these eight students represented the extreme scores on the CEDA and were interviewed to obtain their perceptions of creativity in engineering design. The findings of the interviews are compared between students of high and low creativity. The students selected for interviews and their respective CEDA scores are shown in Table 7.

Table 7
CEDA Scores of Students Representing Extreme Scores

<table>
<thead>
<tr>
<th>Student</th>
<th>Score</th>
<th>Student</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harold</td>
<td>207</td>
<td>Leslie</td>
<td>50</td>
</tr>
<tr>
<td>Harry</td>
<td>207</td>
<td>Lance</td>
<td>48</td>
</tr>
<tr>
<td>Hannah</td>
<td>187</td>
<td>Liam</td>
<td>48</td>
</tr>
<tr>
<td>Herman</td>
<td>178</td>
<td>Leann</td>
<td>42</td>
</tr>
</tbody>
</table>

All names shown in Table 7 are pseudonyms I assigned each student for this project. Given the rather homogeneous nature of the original sample of 42 students, the 8 students representing the extreme scores shown in the proceeding table were all
homogenous with respect to the rest of the group. Specifically, all 8 students were between 18 and 24 years of age, all students were Caucasian except for Hannah who was Hispanic, and all students had a senior class rank.

The top scores comprising the high-scoring group are 207, 207, 187, and 178. The bottom scores comprising the low-scoring group are 50, 48, 48, and 42. The low-scoring group, with a mean score of 47.00 and standard deviation of 3.46, exhibited little variation with respect to group scores compared to the high-scoring group, which had a mean total score of 194.75 and standard deviation of 14.61.

Given the nature of the CEDA, the lowest total score for each participant could be zero because of non-completion. In theory, the highest total score could reach infinity. This is because the nature of the fluency score is a total count of all of the design details a student is able to come up with; thus, the fluency score is limited only by a student’s creativity. The above scores represent total scores, and thus are reflective of each student’s ability to come up with many solutions to the problems presented. Moreover, the total scores are a reflection of each student’s ability to come up with solutions that are diverse, novel, and useful. The divergent-thinking scores should be viewed relative to the other scores in the sample rather than against any external benchmark or standard.

Comparison of Perceptions of Creativity among High- and Low-Scoring Groups

The following section presents a synthesis and comparison of the data collected during the student interviews conducted during the weeks of March 9 to 20, 2015. The responses were categorized in terms of the perceptions of creativity in engineering
design that were of interest in this study: (a) students’ definitions of creativity with respect to engineering design, (b) perceptions of the importance of creativity during the engineering design process, (c) perceptions of their own creative self-efficacy, and (d) perceptions regarding the value they felt engineering faculty placed on creative thinking and the degree to which they felt creative thinking was encouraged in the engineering classroom.

**Definition of engineering design.** Because this study involved perceptions of creativity in engineering design, it was important to first understand what the term engineering design meant to each of the students interviewed. All eight students interviewed had similar and consistent definitions of engineering design. Each student referred to engineering design as either a methodology or process that engineers go through when solving problems. In every response, the phrase “it is how engineers solve problems” came up repeatedly. According to the students, this problem-solving process could result in a manufactured part or prototype, a computer program being written, some basic calculations done only on paper, or even just a recommendation given to solve an immediate problem on the shop floor. Leann succinctly described engineering design:

> It’s everything that goes into designing a solution to a problem, from thinking up a possible solution, to testing it, to building a prototype, to manufacturing it, and going through several iterations if needed. It’s all of that. There has to be a problem though; without a problem, there is no engineering and therefore no engineering design. (1Leann.1.3)

**Definition of creativity in engineering design.** Students were asked to identify the characteristics that constituted a creative engineering design and the characteristics
of creative individuals. Students were asked whether individuals are born with creativity or whether creativity is a skill that could be developed. Both groups had similar responses regarding what it means to think creatively during the engineering design process, how they characterized creative individuals, and whether creativity is an inborn trait or a skill that can be developed.

**Characterization of a creative engineering design.** Table 8 shows a synthesis of the themes identified for both the high- and low-scoring groups with respect to how students characterized a creative engineering design. When asked what characteristics constitute a creative engineering design, several common themes emerged among members of the high-scoring group. First, all four students began the interview by describing what a creative engineering design is not: A creative design does not have to be something completely original that has never been done or seen before, although they felt this would certainly be creative if it solved the problem at hand. All four students described a creative design as something that most often resulted from incremental modifications to existing technologies. Harold stated, “Incremental but effective changes are probably the most common type of creativity in engineering design” (1Harold.2.2).
Table 8

*Students’ Characterization of a Creative Engineering Design*

<table>
<thead>
<tr>
<th>High-Scoring Group</th>
<th>Low-Scoring Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Incremental but effective changes</td>
<td>• Incremental but effective changes</td>
</tr>
<tr>
<td>• Innovative</td>
<td>• Innovative</td>
</tr>
<tr>
<td>• Outside of the box</td>
<td></td>
</tr>
<tr>
<td>• Unorthodox</td>
<td></td>
</tr>
</tbody>
</table>

Hannah stated similar thoughts:

I don’t really think a creative engineering design has to involve new or even completely original ideas. I kind of think creativity or creative design occurs on the shoulders of small improvements to technologies that are already out there. I mean, don’t get me wrong, when someone creates a brand new technology, that’s definitely something creative, but I just can’t help but think that something must be said for an engineer who can look at a process that already exists and works, you know, and makes that process better or more efficient. I’ve always admired that ability. I mean, think about it, when you’re looking at an existing process that works just fine, it’s hard to think outside the constraints of that existing system. (1Hannah.2.1)

These sentiments were echoed by Herman. He cited Henry Ford as a perfect example of someone who is considered creative, not because he invented anything, but because he took an existing design and figured out how to manufacture it more efficiently and effectively. Herman said,

To me, Henry Ford is probably the perfect example. He didn’t invent the automobile, but by developing the concept of the assembly line, he was able to make his product more affordable to his customers. Not to mention the efficiency this added to the manufacturing process. It’s just my opinion, but I don’t think anyone would argue about Henry ford being a creative person. (1Herman.2.9)
When asked what characteristics comprise a creative engineering design, several keywords were mentioned by all four members of the high-scoring group, including innovative, unorthodox, against the norm, and outside of the box. However, along with these characteristics, they all stated that, above all, the design must actually solve the problem. Two of the four indicated that perhaps even more than just simply solving the problem, a creative design should perform more effectively, efficiently, reliably, and even economically compared to any similar design that came before it. Harold felt a creative design is also one that is the most simplistic design, simplistic in terms of overall functionality as well as ease of manufacturability. Harold stated, “Anyone can design something that is incredibly complex, but being able to design something that is very simple, yet solves a complex problem, that is creativity right there” (1Harold.2.3).

Although three out of the four students in the high-scoring group indicated that a creative engineering design does not have to be completely original, Harold felt differently. Harold defined a creative engineering design as something that was completely original and solved a problem. He cited the telephone as an example of a truly creative idea:

I think the most creative designs are those that are not influenced by prior inventions. Take the telephone; it truly is creative because there was no such thing like a telephone before it was created. Think about it, all telephones that came after the original, I guess except for cellular, were just improvements and new innovations on the original design. Don’t get me wrong, all the later phones are still creative, but they’re definitely not as creative as the first phone invention was. Bell took a societal problem like being able to communicate quickly and effectively over large distances, and gave society a solution to the need by inventing the telephone. (1Harold.3.2)
Harold further indicated there are certain levels of creativity, with a completely original design that solved a problem being the most creative, while a design resulting from an incremental change would be considered creative but less so than a completely original design, so long as the change resulted in some type of improvement to a design.

All four students in the low-scoring group used many of the same descriptors as those given by the high-scoring group to define creativity within the context of engineering design. Descriptors such as innovative yet functional, economical, and practical were cited most frequently.

Similar to the students from the high-scoring group, three of the four students within the low-scoring group stated that a creative design does not have to be something completely original but could be the result of incremental changes to a design that resulted in a more innovative product. Liam, however, was Liamant about the how the word creativity seems to be thrown around very loosely. Liam felt that for something to be truly creative, it must be a design that is original and does not borrow ideas from designs that have been proven in the past. Liam summarized this idea:

You know, there is definitely a fine line here, because all engineering designs basically have their core principles or laws that they are designed to satisfy. But I think it’s how you satisfy these principles that sets a creative design apart from one that’s been done in the past. I guess a good example would be that all bridges are designed to support some maximum weight, whatever it is, in various conditions, but there’s all sorts of different types of bridges that satisfy this constraint in different ways – that right there, that’s what I think sets them apart. I kind of feel like it’s an attitude of not just accepting a design that has been used for ever, but you know, having this mentality of wanting to go against established designs or conventions, that to me is creativeness right there.

(1Liam.3.6)
All others in the low-scoring group emphasized that ultimately a creative design is the result of being able to see where changes could be made when others could not see, whether it was saving weight, making it easier to manufacture, or even simply changing the aesthetics. In sum, students in this group said a creative engineering designer was someone who figured out “how to do it” when others could not. This was described by Lance when he said “creative engineers just always seem to have a solution ready to go know matter what the problem. I see this all the time where I work, give them a minute and they give you like 5 solutions to a problem” (1Lance.2.12)

**Characterization of creative individuals.** Table 9 shows a synthesis of the themes identified for both the high- and low-scoring groups with respect to how students characterized a creative individual.

**Table 9**

*Students’ Characterization of Creative Individuals*

<table>
<thead>
<tr>
<th>High-Creativity Group</th>
<th>Low-Scoring Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Confidence and intelligence</td>
<td>• Confidence and intelligence</td>
</tr>
<tr>
<td>• Ability to visualize the problem</td>
<td>• Excellent visualization skills</td>
</tr>
<tr>
<td>• Not afraid to take risks</td>
<td>• Drive and motivation to succeed</td>
</tr>
<tr>
<td>• Having foundational and prior knowledge about the problem</td>
<td>• Imagination</td>
</tr>
<tr>
<td></td>
<td>• Ability to see improvements where others could not</td>
</tr>
</tbody>
</table>

When asked about the characteristics of creative people, all students in the high-scoring group used the same descriptors. Confidence, intelligence, not being afraid to
take risks, the ability to think outside of the box, and imagination were the most commonly used descriptors. Moreover, every student in the high-scoring group also emphasized the importance of foundational knowledge, which is the type of knowledge typically gained from formal study, as well as prior knowledge about the problem they were investigating. They all cited these two factors as central to being able to think creatively.

In addition, all four students in the high-scoring group listed the ability to visualize the problem as central to creativity. When asked to elaborate on what was meant by visualization skill, each student in the high-scoring group described it as being able to visualize the structure of an object and its relationship to other objects and make modifications to it purely in one’s head. Each student described this ability as being important to help creative people see problems where others do not and come up with solutions when others cannot.

Hannah described creative people in terms of unconventional or eccentric personality characteristics:

I think creative people can often be a little eccentric, at least that’s my experience. But I think that helps or enables their creativity. Also, they don’t usually care what people say about their design because they’re so confident. I also sometimes think this is detrimental though, because I’ve seen where a lot of times people like that can be pretty headstrong and resistant to input from others. (1Hannah.2.10)

When asked about what characteristics creative people tend to have, all four students in the low-scoring group gave many of the same descriptors as those given by the high-scoring group. Descriptors such as confident, excellent visualization skills,
driven and motivated to succeed, and the capability to think outside of the box were the most commonly stated. Moreover, the word imagination was repeatedly used by three of the four students in this group as a descriptor of creative people. For example, Leslie stated:

Creativity, to me at least, involves imagination to see beyond what is currently being done. I could give you an example. I used to co-op at a manufacturing plant that made wheelchairs, and something so simple as two wheels and a seat got designed into dozens of different types of chairs, not to mention different options to better fit the customer’s needs, like, a lift for the seat or even just the color to personalize it. I think it really takes a creative mind to come up with ways to change or modify something so simple, you know, to make it better. (1Leslie.2.12)

**Perceptions of creativity as an inborn trait or developed skill.** Table 10 shows a synthesis of the themes identified for both the high- and low-scoring groups with respect to students’ perceptions of creativity as an inborn trait or a developed skill.

Table 10

*Students’ Perceptions of Creativity as an Inborn Trait or a Developed Skill*

<table>
<thead>
<tr>
<th>High-Scoring Group</th>
<th>Low-Scoring Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can be developed</td>
<td>Can be developed</td>
</tr>
<tr>
<td>Some have a “gift” for creativity</td>
<td>Some have a “knack” for creativity</td>
</tr>
<tr>
<td>Environment must be supportive of creativity</td>
<td>Environment must be supportive of creativity</td>
</tr>
<tr>
<td>Personality characteristics must be right</td>
<td></td>
</tr>
</tbody>
</table>

109
When asked whether they felt creativity was something one is born with or a skill that could be developed, all four students in the high-scoring group agreed that creativity can be developed, but that it does indeed come more naturally for some than for others. Harold summarized:

Some people are just born creative in certain areas, no doubt about it, that’s just the way their brain behaves, they are born problem solvers. I definitely think others can become creative if they work hard at it; you know, build the proper foundation of knowledge, I guess. You could compare it to sports in a lot of ways. For some kids, you can see that some possess some sort of natural talent to a sport that others just ain’t got. But with a lot of practice and hard work those kids that may lack what you might call god-given talent can still become very skilled players. (1Harold.3.2)

Although some may have a “gift” for creativity, as two of the four students in the high-scoring group mentioned, all four students in the high-scoring group stated they felt creativity can be developed, if both the personality and environment are right. Harold described the importance of the environment:

I believe creativity definitely relies on a supportive environment. I mean, if new ideas are ridiculed, then creativity is going to be stunted because a person would be less likely to pitch new ideas, I guess this is where not being afraid to take risks helps out a lot. (1Harold.2.10)

All four students in the low-scoring group stated they believed all people are born with the ability to be creative, and after birth, the environment influences whether such people stay creative or not. For example, Leslie stated:

I think all of us are born with some creativity, but as we grow and gain knowledge that creativity can grow with us. But I think if we were to stop imagining or gaining knowledge, then we lose the ability to think creatively. Kind of like how when we were kids we read books and our imaginations grew. The same thing happens with crayons and paper or building blocks. We try new things and ask questions. If you continue that throughout your life, you can be as
creative as you like, but if you just stop imagining things, you lose a lot. (1Leslie.3.2)

Lance too had a perspective on how one can be creative even if one was not “born” to think creatively within a particular domain. He stated:

I think while some people may be born with a natural sense for creativity in engineering, creativity is something that can be developed and strengthened over time. I guess what I mean is that someone without the “knack” for spontaneously coming up with great ideas can take more of a strategic and scientific approach to design, like we learn in school, and still have the same success as a more naturally creative person. (1Lance.2.16)

Lance believed that deficits in creativity could be overcome by having a solid theoretical understanding of the problem at hand, thus allowing a designer to develop a strategic approach to engineering design. Lance believed that engineering fundamentals, such as those learned in engineering school, are central to being creative in engineering design work, even if one is not someone who can “spontaneously” come up with ideas. Lance elaborated by stating “if you take a strategic approach to design, and analyze the situation carefully, you know, then you are likely to arrive at the same conclusion or same solution as the more creative engineer did. It’s all about strategy and logic, and knowing the principles I think” (1Lance.2.4)

**Perceptions of the importance of creativity in engineering design.** Table 11 shows a synthesis of the themes identified for both the high- and low-scoring groups with respect to students’ perceptions regarding the importance of creativity during the engineering design process. Clear differences exist between the high- and low-scoring groups with respect to their perceptions of the importance of creativity in engineering design. The high-scoring group was much more liberal in their perceptions about the
importance of creativity in engineering design, believing that it is always important to think creatively when designing, as well as during general problem solving. They viewed creativity as a way of thinking and not just the result of a design. The low-scoring group, in contrast, was considerably more conservative in their perceptions about the importance of creativity in engineering design, believing that one should be creative only when necessary and that an engineer should not attempt to reinvent the wheel by making radical design changes.

Table 11

*Students' Perceptions of the Importance of Creativity in Engineering Design*

<table>
<thead>
<tr>
<th>High-Scoring Group</th>
<th>Low-Scoring Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Always important during engineering design</td>
<td>- Important during design, but not always necessary</td>
</tr>
<tr>
<td>- Opens up design to more possibilities</td>
<td>- Engineers should not try to reinvent the wheel</td>
</tr>
<tr>
<td>- Allows for improvements and betters the engineering profession and society as a whole</td>
<td>- Creative engineers can provide fresh new ideas to stagnant companies</td>
</tr>
</tbody>
</table>

All four students in the high-scoring group believed it is always important to be creative during the engineering design process. Each student in the high-scoring group indicated a perception that creativity is what allows an engineer to think beyond current practice, allowing for technological advancement. Three of the four interviewed in this group spoke of personal advancement as well, mentioning that the ability to think and design creatively allows an engineer to advance professionally more quickly by being
able to pitch ideas no one else had produced. Harold emphasized the importance of creative thinking when designing. He stated:

Without creativity, the design will end up becoming the same exact design as something else. It won’t have any originality, and then of course probably no marketability. It will be the same exact product as something else and others will look down on you for copying someone else’s creativity. I guess I just think being creative opens up the design to more possibilities, things like better efficiency, lower costs, sleeker looking designs, and other things. I think you can only improve something by looking at it a different way than before, and that’s what creativity gives you when coming up with an engineering design. (1Harold.2.15)

Creative thinking, however, is not just about coming up with engineering designs that are new and different. Several students described how creative people excel during problem solving activities, emphasizing that creative people can come up with solutions to problems quickly. Harold summed this up well when he stated,

Creative people are idea generators. A creative person will place more ideas on the table; then those ideas might spark other ideas in other people’s minds, so creative people cause others to excel. I’ve seen this happen a lot during my co-op. (1Harold.3.2)

Hannah described how even though the decision to come up with a creative new design ultimately depends on the type of firm at which one is employed and what they are designing, creativity can be very useful during problem solving because, in her experience, this is primarily what engineers are called upon to do more than anything else. She described the benefit of being able to think creatively all the time:

I work in a manufacturing engineering co-op. I don’t know how many times engineers are called to put out fires; it seems that that’s the only thing engineering does where I work is put out fires that occur in a process, fix problems, and come up with solutions, sometimes immediately, on the spot. Creativity is important in manufacturing settings because without it, we would just continue doing the same things over and over and we would essentially be putting out the same fires every day. I think creativity enables us to find new
solutions to reoccurring problems. I think I mentioned before that I don’t think we have to come up with something entirely “new” to be creative, but it’s like incredibly important in engineering to at least try to think outside the box whenever possible or at least whenever you’re allowed at your company (1Hannah.2.16).

Ultimately, all four students in the high-scoring group believed it is always important to be creative, whether this means during engineering design situations or during routine problem solving on the shop floor. They described how a creative mind always gives an engineer an edge up in business. It is “the X factor,” as Harold described it “which constantly allows us to make improvements and better the engineering profession and society as a whole” (1Harold.2.12). Harold described how engineers are frequently called upon to solve problems where no one else can, often in situations that are very complex. He cited the Apollo 13 space shuttle as an example of the utility of having creative engineers on staff to be able to solve problems that on the surface seem very complex, but need to be solved, sometimes immediately. Harold illustrated with an example:

When Apollo 13 was running low on oxygen and had too much carbon dioxide in their space shuttle air, it was up to some scientists and engineers to come up with a way of cleaning and filtering the air. They only had a very specific set of supplies to work with because they had to use what the astronauts had available to them. Think about it, if you had just a bunch of people that were not creative and only knew what was in the textbook, they would have never got the job done. That’s an example of being very skilled in applying technical knowledge in a creative way. (1Harold.3.11)

Although all four students in the low-scoring group also thought creativity was important during engineering design work, they each stated they believed it was not always important, and it was this point that each one of them emphasized during the
interviews. For example, Liam reinforced the sometimes-negative perception of creativity by suggesting that a creative design can sometimes be too radical, too expensive, and end up costing the firm more money in the long run by increasing production and prototyping costs. Liam stated “creative engineers come up with some crazy ideas, and if they sell people on them and they don’t work, I’ve seen companies go bankrupt because of crazy ideas that were originally thought to be creative, but they were just bad ideas that weren’t practical” (1Liam.3.14). Lance supported this notion when he stated the old adage “an engineer should not try to reinvent the wheel” (1Lance.3.2). Lance had a rather interesting take on whether an engineer should always try to be creative during engineering design activities:

> Think about it, we’re in a period in history where there’s so many products, designs and methods out there. An engineer can just choose from something already created or thought of and change it or mold it for the task at hand. I don’t think this is copying at all; I think it’s just being resourceful and using the resources of the modern age. I guess it may not be creative but it’s definitely smart. It’s smart because it’s effective in cutting costs and time. Okay, don’t get me wrong, I think being creative is important for the profession, yeah, it’s just not always necessary. If you’re just maintaining something like a system, then you just apply what you learned in your degree. But if you’re curing cancer or developing a structure to withstand an 8.0 earthquake, then yeah, you’re probably going to need the ability to think outside the box, outside the textbook, you know, because you’re dealing with something that’s never been done before. It all just depends, but I think some engineers get carried away thinking they always need to design the latest and greatest when old technologies and designs work just fine. (1Lance.3.6)

Liam brought up the idea of simplicity again, suggesting that the best design is often the simplest one or the one that requires no creativity whatsoever. Liam emphasized the importance of knowing when to be creative and when to do things the way they have always been done in the past. He stated:
I think it’s important to know when creativity or any kind of change isn’t needed though. For instance, when a machine needs a specifically designed part in order to work, don’t get all creative and fancy, just design the part to the right specs and get the job done and move on. (1Liam.2.9)

Leslie felt that creative people are sometimes more distracting than anything else. She emphasized during the interview that she had known many creative people who were full of ideas but rarely had the knowledge to implement them. She believed engineering design should rely on a more logical and systematic process rather than on a creative one. She summarized:

I feel like it’s more important to have a solid idea that’s realistic, you know. I feel like creative people have a lot of ideas but no way of getting them done. This just wastes time and money. I’ve seen it so many times at my co-op. Engineering is very logical, step by step, you know, there’s a process. Creativity I think sometimes disrupts that process more than makes it better. (1Leslie.3.2)

When asked about whether creativity is important to the engineering profession, each student felt that creativity is beneficial if it is explicitly needed. Each student described the need for creativity if new technologies are needed or if a company wants to go in a new direction. More ideas on the table are always better than just one, but the primary theme emerging from this group was, “Creativity is great if and only if it is coupled with logic and reason” (1Leslie.3.4). Moreover, each student in the low-scoring group seemed to emphasize creativity as a type of thinking process that could aid in problem solving and idea generation rather than emphasizing its utility in designing next-generation technologies. In other words, the low-scoring group seemed to have a more practical view of the benefits of creative thinking. For example, Lance stated:

I think creativity is an important trait for any engineer to have as long as it’s not too radical, you know. A creative engineer can be an extremely valuable addition
to an engineering team, mainly because of the fresh ideas they bring to the table. Sometimes companies can be in a rut of doing things a certain way just because “that’s the way we’ve always done them.” I have heard that so many times, especially from older engineers at my co-op. I think sometimes it takes a fresh outlook by a creative engineer with creative new ideas to snap them out of it. I think this is when a creative engineer is good to have on staff. (1Lance.3.4)

**Perceptions of creativity in the mechanical engineering classroom.** Table 12 shows a synthesis of the themes identified for both the high- and low-scoring groups with respect to students’ perceptions of creativity in the mechanical engineering classroom.

Table 12

*Students’ Perceptions of Creativity in the Mechanical Engineering Classroom*

<table>
<thead>
<tr>
<th>High-Scoring Group</th>
<th>Low-Scoring Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Professors value creativity</td>
<td>• Professors value creativity</td>
</tr>
<tr>
<td>• Limited opportunities to be creative</td>
<td>• Limited opportunities to be creative</td>
</tr>
<tr>
<td>• Design problems too constraint-laden</td>
<td>• Design problems too constraint-laden</td>
</tr>
<tr>
<td>• Development of creativity not school’s primary job</td>
<td>• Development of creativity not school’s primary job</td>
</tr>
</tbody>
</table>

All students from both groups shared the same perceptions. None of the students in either group believed the mechanical engineering program developed their creativity. Although each student in both groups believed their professors wanted them
to be creative and valued creative thinking, they felt the program offered little to no opportunity to be creative beyond the basic freshman mousetrap design activity and the senior design project. The lack of development of creativity was primarily blamed on the lack of open-ended problems found in nearly every class, and when problems were open-ended, several students from both groups indicated they felt the problems were too constraint-laden and relied more on synthesis of known procedures rather than allowing more divergent-type thinking to take place.

However, each interview with students from both groups culminated in a slight digression from their previously mentioned perceptions. All students in both groups indicated they believed it was not the professor’s job to teach creativity; rather, the focus in the classroom should be on the fundamentals—the science behind the design—and that it is ultimately up to the student to then utilize this knowledge in a creative manner when necessary. Thus, a dichotomy seemed to surface in the students’ responses: On one hand, each student desired more opportunities to express creativity through open-ended design projects and real-world problem solving. On the other hand, they all agreed that an engineering program’s primary function was to develop the foundational skills in engineering science necessary for creative thinking.

All four students in the high-scoring group believed their professors wanted them to be creative, and yet each student in the high-scoring group mentioned that they felt there were very few opportunities to be creative throughout most of the coursework. Closed-ended homework assignments and a lack of design projects were cited as the primary reasons for this perception. Herman felt the professors wanted
students to develop the ability to think creatively. However, because of the nature of the subjects that comprise mechanical engineering (such as math and physics, where students perceive only one right answer and a logical solution path to it), Herman felt there was no way to be creative when solving problems in such courses.

Herman believed there is no way to think creatively about textbook math and physics problems. He stated:

I think we need more design projects. I bet professors probably think students could get creative when solving problems in the textbook if we wanted to, but these kinds of problems only encourage working backwards from the answer in the back of the book or using the solutions manual. I’m sorry, but that’s just the way it is. Textbook problems just encourage using the solutions manual.

Students are more concerned about receiving an A in the classroom as opposed to a full understanding of the material. (1Herman.3.9)

Hannah expressed a similar line of thinking as she noted how several of her professors had stated that students should work on coming up with innovative solutions to engineering problems. She said:

Many of my professors have harped on the fact that in the real world we will not have a solution manual or textbook solution to a problem, so we should learn how to think outside of the box. But the classes focus mostly on theory and problems from the book, and we don’t have many “design” projects in any classes. We mostly do projects in MatLab. We are required to do one design project where we complete a project from design to fabrication, I’m in that now, but that’s it, that’s all we do. In school, I have just learned theory and fundamentals, which don’t get me wrong is important to creativity, but there is no opportunity to utilize it in real world design situations during school. Fortunately, my co-op has allowed me a lot of opportunity to think creatively. (1Hannah.4.2)

Harold states he was not encouraged at all to be creative. He stated:

The professors generally just give the problem and ask for a generalized way of going about it, which doesn’t leave a lot of room for creativity, I’m sorry. In most cases, our homework problems and assignments have a specific answer that you
are trying to find by going about a method that was presented in class. I think they have done a good job of teaching us how to analyze problems, definitely, but not really how to be creative with designs. I think I would be great at picking out the best of two designs, but coming up with completely original designs, well if I could, it would be because I’m naturally creative to start with. (1Harold.3.12)

Many stated that programming courses that utilized MatLab or CNC programming had been the only opportunities to be creative thus far. For example, Harold stated:

In the classroom, there was not a lot of opportunity to get creativity; everything had a definite answer and essentially one way to do it. I had a couple design projects like a CNC project, the mousetrap during freshman year, and of course senior design, but other courses had very little opportunity for design, much less creativity. Programming in MatLab is nice because there are many different ways to get the same answer, some better than others, some are just outright inventive. (1Harold.4.1)

While some professors were perceived as failing to give students opportunities to be creative in the classroom, Harold spoke about professors in a completely different light when referencing his design teams. Harold discussed at length how he was thankful to be on the design teams, such as the Baja and Formula One teams. These teams helped him develop creative-thinking skills. He described how his professors encouraged him to be creative throughout the whole design process on these teams.

The professors involved in these teams were always willing to accept multiple designs or ideas. Many of the projects were left more open-ended so we could figure out things on our own. This allowed us to be creative and come up some pretty great new ideas for a project. The professors also encouraged us to be creative and think outside of the box for these projects. They were always ready to help me solve problems or go about it in different ways. Doing real world design like this with awesome professors to mentor us has definitely developed my creativity. (1Harold.4.4)
Although all four students in the high-scoring group believed the mechanical engineering program had not developed their ability to think creatively about engineering design problems, each student did not believe it was the program’s responsibility to develop such a skill anyway. Each student in the high-scoring group believed the function of school was more about teaching the fundamentals and developing a logical and systematic approach to solving engineering problems, rather than on developing students’ ability to think creatively when working on engineering problems. Herman commented on school and creativity. He stated:

I personally think the college setting is often a creativity killer. As I said before, I think a lot of it is due to material we learn in class. I mean, think about it, the content in most of our classes has barely changed over the past century. But I also think a lot of this is due to how college works. Think about it, creativity requires that you take risks, but it’s hard to take risks when you have a problem with only one right answer, you know. I also think tests and most homework kill creativity because there is only one way to do things to get a good grade. More open-ended problems and assignments could definitely help the program turn out more creativity in its students. (Herman.4.2)

Herman followed up on this statement by discussing what he perceived to be the difficulties in terms of implementation if the university were to require more open-ended design projects and homework into its curriculum:

Of course, you know, it’s funny, I know what I just said, but I think if we were required to do more open ended problems, and real world problems, you know, non-text book problems, the students would revolt! I’d say for the vast majority of students, the ME program is a stepping stone to a career, a means to an end, you know. Even me, I sometimes find myself forgetting that I came here to gain career skills, not just get a degree. I can tell you for sure that for some students, it’s more about getting good grades and getting a piece of paper than it is gaining career skills. That’s why, and I’ve said this to a lot of people, I think an ME degree just shows you’re capable of becoming an engineer but it definitely doesn’t mean you are one. Just like I don’t think you’re an engineer until you get out on the job and start doing engineering work, I would also say you can’t
develop creativity until you get on the job and start thinking about real
problems. (1Herman.4.6)

Many of the sentiments echoed by the high-scoring group were also mentioned
by the low-scoring group. In particular, each student in the low-scoring group perceived
little opportunity for creativity in the mechanical engineering program. Similar to the
high-scoring group, this group cited examples such as too many closed-ended
homework assignments and design projects that placed too many constraints on the
student. Leann felt that even when she was given what she termed “real world design
projects,” an overabundance of constraints made being able to come up with creative
solutions to the problem a near impossibility. She said an overabundance of constraints
made her feel as if there were still only one correct answer, similar to that of a typical
textbook-type problem. She stated:

Every single one of the projects I have ever gotten throughout my college career
has had like a strict structure, an exact goal, and a procedure to go with it. Let’s
face it, when you have a project with so many restrictions, you aren’t given much
room for creativity, except for maybe the way we present the final solution. I
know structure and constraints are important in engineering though. When we
get jobs, the company may have strict requirements on their procedures and
paperwork and whatever, but in the end, if we design something new, we must
use some sort of creative mind. I definitely think our professors show us the
structure you know, but they don’t stretch our creativity enough. (1Leann.4.1)

Leslie felt despondent by the lack of design opportunities she experienced in
school. She stated:

I wish there were more design opportunities, so maybe I could have developed
better design skills, and possibly creativity, who knows. So far, programming in
MatLab and the mouse trap project we did freshman year has been the closest
thing to design I have experienced. During my co-ops, I didn’t see many design
opportunities either. Most of the time I just watched different processes to see if
changes could be made. It kind of saddens me that I haven’t gained any real
design experience. (1Leslie.4.3)

Liam had a completely different perspective. He felt he was encouraged by
professors to be creative. He believed he was encouraged to tackle open-ended design
problems any way he saw fit. Even though many of the design problems had numerous
constraints given in the problem statement, he believed that was the nature of
engineering work, and creativity came from being innovative within the required
constraints. About his classmates and creativity, Liam said, “I am willing to bet others
would probably disagree with me, but that’s because most of my friends don’t even try
to be creative, they would rather just ‘get things done’ without thinking creatively”
(1Liam.3.11).

Moreover, Liam believed it was not the professor’s job to teach creativity, but
rather that they should teach the fundamentals, the science behind design, and allow
the student to then utilize this knowledge in a creative way whenever necessary. Leslie
also mentioned the importance of fundamentals by saying, “Without fundamentals, you
can’t think creatively anyway. I don’t think it’s the schools job to teach creativity, it’s up
to the person to use the fundamentals we learned in school in a creative manner”
(1Leslie.4.6). Liam believed that professors did see the value in creativity and was
encouraged to become involved in the many design teams available to engineering
students by several professors. In his words, “Now, that is where creative thinking can
really be developed!” (1Liam.4.2)
Similar to the perceptions held by others in the low-scoring group, Lance felt that although he did not believe the mechanical engineering program developed his creativity skills directly, he believed the program allowed him to develop other, more important skills and that this may have indirectly developed his creativity as well. For example, Lance stated:

I would have to say I think the ME program has indirectly helped me to be more creative. I guess what I mean is I think that the ME program taught me how to focus my creativity into solid, more useful designs. I kind of feel like I would now be more able to easily see any potential flaws in different designs, and select the best design from several choices. That, to me at least, is way more important than creativity, it’s just a more practical skill that I think employers would rather see in an engineer they hire. (1Lance.4.7)

**Self-perception of creative abilities.** Table 13 shows a synthesis of the themes identified for both the high- and low-scoring groups with respect to students’ self-perceptions of their creative abilities.

Table 13

*Students’ Self-Perceptions of Their Creative Abilities*

<table>
<thead>
<tr>
<th>High-Scoring Group</th>
<th>Low-Scoring Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Confident in their creative abilities</td>
<td>- Lacked confidence in creative abilities</td>
</tr>
<tr>
<td>- Interest in understanding how things work</td>
<td>- Prefers a systematic and logical approach to problem solving</td>
</tr>
<tr>
<td>- Enjoy thinking outside of the box</td>
<td></td>
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</tbody>
</table>

It was clear that in terms of creative self-perceptions, the high-scoring group felt more confident in their abilities related to creative engineering design. The high-scoring
group clearly envisioned themselves as naturally creative and felt confident in their creative abilities, especially in terms of solving mechanical problems such as the ones most often encountered in engineering practice. The low-scoring group clearly felt less confident in this area—two individuals stated they lacked the ability to think creatively during engineering design altogether.

All four students in the high-scoring group classified themselves as creative individuals. Further, students in this group felt they were creative in other areas as well; it was simply a matter of where their interests lay. For example, Hannah stated that she loved both art and engineering, and both elements allowed her to think creatively:

> I would have to say I have always been creative when it comes to art, and I have a love of science as well. You could definitely say I went into engineering to apply my creativity to a scientific field. I constantly come up with new designs, procedures and solutions to problems at my co-op and work, and I love it, I love the challenge. (1Hannah.4.5)

This idea of creativity and interest came up several times with each student in the high-scoring group. For example, Harold stated:

> I have kind always been creative ever since I was a little kid. My parents always encouraged me to be creative. Man, I tore things apart and put them together again so many times when I was younger, I redesigned so many things to make them better. But I’m creative only when it comes to mechanical type things, you know, not so much in other areas, of course, it depends. If I’m interested in an area, I can be creative when solving problems, I think. If I’m not interested, I just don’t care to be creative. I like mechanical stuff, and I understand it well, so I’m more creative that way, you know. (1Harold.4.7)

These sentiments were echoed by Harry, who characterized himself as the prototypical future engineer when he was a child. Harry stated:

> As a kid, I was the stereotypical future engineering student that constantly was taking things apart and putting them back together. It’s funny, my Xbox seemed
to be in pieces more often than it was together and my paintball gun was constantly apart on the kitchen table. I know these kinds of things helped develop my creativity. I’m creative primarily when it comes to mechanical type problems though; I guess that’s why I went into mechanical engineering. It just depends on the area, like music, no way, no talent whatsoever, but mechanical type stuff, very much so, I have a passion for it, it very interesting. (1Harry.4.9)

In terms of the group as a whole, all four students repeatedly stated they had always had confidence in themselves and that they loved thinking outside of the box and trying new things, even if they thought it might result in failure. For example, Herman stated “if I hadn’t tinkered with stuff as a kid, I probably would have no imagination right now, I really think tinkering with toys and other stuff as a kid really helped my design skills” (1Herman.4.15).

The low-scoring group diverged with respect to their self-perceptions regarding their creative abilities. For example, Liam and Lance felt they were not naturally creative people and often found it difficult to think outside of the box when solving problems, in particular, mechanical engineering problems. Liam elaborated by stating:

I’m doing a co-op right now, and I’m finding out I’m not really a creative person when it comes to mechanical type stuff. Don’t get me wrong, I love engineering and solving problems, but I feel I’m more of a logical type problem solver, not really creative. I love music, and have a real passion for it; I can write my own songs and develop original music. I love engineering, but I guess I don’t have a passion for it, I’m not sure, but my brain doesn’t think like other really creative mechanical types. (1Liam.3.11)

In a similar manner, Lance, although he explicitly stated that he was not a naturally creative person, felt that he was able to overcome this through a systematic approach to problem solving. For example, Lance stated:

No, I would not consider myself a naturally creative person. I have never been one who was able to come up with ingenious solutions, but I feel like I have
developed my creativity to the point that I’m able to, kind of strategically and scientifically attack design problems, and then come up with good, sound, and practical solutions. (1Lance.3.12)

Both Leslie and Leann felt they were very creative. For Leslie, however, a lack of confidence and fear of criticism often prevented her natural creativity from coming through. She felt she always had creative ideas, but she feared criticism if she expressed them. She summarized, “It’s a confidence thing, I guess. I hate it, because I have a lot of good ideas” (1Leslie.4.1). She also stated jokingly that her ideal situation would be to be asked to come up with an idea immediately, with no time to think about potential criticism. She gave the following scenario to illustrate:

Just last month, I was wearing a pair of military style boots when my shoe lace ripped right in the middle. Well, I went over to the library and asked if they had any rubber bands or paper clips so I could figure out how to tie my shoe so it wouldn’t be so loose all day. The only thing close to what I wanted was one extra-large rubber band. I took it and wrapped it around my leg and all the way down the prongs. It worked perfectly and it was pretty creative if I do say so myself. I told someone later about it and they couldn’t believe I came up with that. The best thing is, you couldn’t tell the difference other than one was black with laces hanging out and the other was tan. It got the job done. (1Leslie.4.3)

For Leann, however, creativity was more of a time issue. She discussed how she felt she had the capability of being very creative when it came to scientific problems that needed creative solutions. For Leann, creativity tended to be a slow process. She illustrated with the following:

The only problem is that I think my creativity is slow. It always just takes me a while to come up with a new idea or a new way of looking at things, you know. Usually my best creativity comes when I let my mind wander and get off track. I bet that sounds strange, but if I think too hard about something, I think I block my creativity and don’t let my ideas flow as well as they should. I know it’s true because I always come up with my best ideas when I am day dreaming and when I am not focusing all of my energy on a certain idea. I probably didn’t do as well
on that test you gave because I need more time to think, if I had more time I probably would have done a lot better. (1Leann.4.3)

Thus, two members of the low-scoring group felt they lacked creative abilities but tended to make up for it with a systematic and logical approach to design and problem solving. The other two members felt they were quite capable of creative thinking in engineering design situations, but lacked either confidence or time to be creative and therefore felt they were often perceived as being less creative than they actually were.

Research Question 3: What are the perceptions among mechanical engineering faculty of creativity in the mechanical engineering program and its development of creative-thinking skills?

In this section, I describe the mechanical engineering faculty members’ perceptions of the importance of creativity in engineering design, as well their perceptions of the extent to which the mechanical engineering program contributes to students’ development of creative-thinking skills. In addition, I describe some classroom practices that certain faculty do to encourage students to think creatively when working on engineering design problems. Note that all faculty names are pseudonyms that were assigned to protect the anonymity of the faculty who agreed to participate in this study.

An overarching theme emerged from faculty in response to the question of whether creativity is important in engineering design. Each faculty member who responded to the questionnaire felt that creativity was an important component of the design process and a skill every engineer should have. Several faculty members
indicated that they believed creativity was a critical skill, and one faculty member in particular said that creativity was a skill that differentiated good engineers from bad ones. Another faculty member indicated that although he felt creativity was important to good design, it certainly was not the only requirement. He elaborated:

Creativity is central to good design. But I also believe that without a thorough understanding of the problem, the science involved with the problems, and what others have done to solve the problem, it is difficult or impossible to be truly creative. (Dr. Regula, questionnaire, March 16, 2015)

These sentiments were echoed by nearly every faculty member who responded to the questionnaire. One faculty member was particularly direct in his perception that although creativity was important to engineering design and the engineering field as whole, it could not take the place of other components necessary for good engineering design work. He further elaborated:

I believe it is important, yes, but perhaps not as important as having a systematic design process and knowing the problem domain which the design is addressing, past successes and failures in the domain, and maybe broad knowledge of other related fields that you can import to the problem at hand. Creativity is definitely one component of the design process, but only one. I just feel it is more important to be able to model either experimentally, mathematically or both, the physics of the concept being designed. That is what we teach in an engineering program. (Dr. Hines, questionnaire, March 18, 2015)

In terms of the mechanical engineering program itself and the extent to which it developed creativity, each faculty member stated in one form or another that they were giving students the skills and knowledge necessary to be creative problem solvers through an understanding of the fundamentals. As several faculty pointed out, it is nearly impossible to think creatively without a basic fundamental knowledge of the problem one is trying to solve. One faculty member indicated he believed it was
important not to “get too carried away” with creativity and lead students to think they could accomplish anything. He mentioned how he made a point to discuss in the classroom how one can and should be creative, but that there were always certain boundaries that one could not cross. For example, he stated:

I teach creativity by talking about the limits of what can be achieved but has not been achieved yet, by showing students what has not yet been done but that is possible. I think people get a little too carried away with creativity though. For example, I know of one university that has a motto for their engineering school such as “think beyond the possible,” this is terrible to tell student engineers. Engineers and scientists do not try to break the first or second law of thermodynamics (beyond the possible) no matter how creative you are, these laws are immutable. I try to show students what is possible, not achieved yet, but a possible goal to shoot for. (Dr. Mure, questionnaire, March 16, 2015)

The primary theme emergent from the faculty responses was that creativity is developed through strengthening foundational skills and imparting knowledge of a systematic approach to design. However, not all faculty members shared the view that creativity could be developed. Two faculty members held the belief that creativity was not something that can be taught, and there probably were no specific courses or activities that could develop it. As one faculty member said:

To tell you the truth, none of the institutions I have been to have focused on creativity. There are no specific curricular activities which can foster creativity. If the student has it (possibly an innate capacity) then it is there. But we do not get engaged in activities that will “render” students creative. Probably the best I can do to induce creativity is to foster teamwork. Creativity is proportional to the amount of debate or discussion taking place among team members. (Dr. Kirk, questionnaire, March 16, 2015)

Another faculty member described his beliefs about creativity and the mechanical engineering program:
I feel like our program enables students to identify the best of candidate designs through theoretical analysis, which is probably more important than creativity anyway. (Dr. Smith, questionnaire, March 17, 2015)

Many faculty members were insistent that they provided students with opportunities to think outside of the box, or at least, beyond the textbook, as one faculty member said. Another faculty member tried to encourage creativity by assigning more real-world problems in his courses. He stated:

I think being creative means that a student should be able to generate new ideas, to obtain new or more accurate solutions. In order to be able to do this, students need to have a good grasp of the fundamental principles (i.e., laws), to have a good sense of applying the laws to generate mathematic descriptions (models or equations), and to have ability to solve the equations to obtain final quantitative solutions. The curriculum and all course work should provide students training in these three aspects. I am always trying to provide more opportunities to my student in my thermal dynamics and heat transfer classes by provide more engineering-related problems, in-class discussions, as well as various form of computer projects. (Dr. Stewart, questionnaire, March 17, 2015)

Several faculty described how they encouraged creative thinking among students by discussing the current state of knowledge in a particular area, leading to a discussion of where they are trying to go in terms of technology or knowledge in general, all while making sure students have a good grasp of the limits or boundaries involved. One faculty member gave the following example to illustrate:

I try to encourage students to think of “new” ways to deal with engineering problems that are important and current, i.e. combined cycle power generation to achieve 60% efficiency and utilize natural gas as the fuel rather than coal to reduce carbon dioxide emissions. Another example is a home heating and air conditioning system that utilizes energy stored in the ground. My efforts in this class are to encourage students to think of getting closer to the limits of what is possible by showing where present energy systems are and what innovations can improve performance to become closer to the efficiency limits set by the governing physical laws. (Dr. Murray, questionnaire, March 17, 2015)
Other faculty indicated they often discussed their current research efforts in particular areas to prompt students’ interest in either thinking about solutions to future problems or perhaps about research in general, which, as several faculty indicated, often requires creative problem solving.

All faculty who responded to the questionnaire indicated they believed they encouraged creative thinking in the classroom, even if it was just conceptually. However, many also felt if a student was not opening his or her mind up completely to what was being discussed in the classroom, than the student could miss the intention of certain discussions or problems assigned in class. As one faculty member indicated,

> If all a student cares about is a good grade at the expense of learning, there is nothing I can do for them, their mind is already made up. However, if a student comes to me with a genuine interest in the subject matter and the desire to learn beyond the textbook, I welcome that. (Dr. Salvino, questionnaire, March 18, 2015)

Although none of the students in either the high- or low-scoring group felt that the mechanical engineering program developed his or her creativity, several faculty members felt just the opposite. Several faculty members admitted they could be doing more in terms of giving students opportunities to work on realistic, open-ended design problems for which any number of solutions was possible. However, several also claimed they routinely attempted to encourage students to think outside of the bounds of existing limits and think divergently about problems during lectures. Several faculty members indicated they felt that if a student was not willing to open his or her mind up to what was being discussed and future possibilities, than the student could miss the intention of problems given and discussions presented during lecture.
Research Question 4: How do perceptions about the mechanical engineering program and its development of creative-thinking skills compare between senior mechanical engineering students and mechanical engineering faculty?

Table 14 shows a synthesis of the themes identified for both faculty and students’ perceptions of the importance of creativity in engineering design. Table 15 shows a synthesis of the themes identified for both faculty and students’ perceptions of creativity in the mechanical engineering program.

Table 14

**Summary of Themes for Students’ and Faculties Perceptions of the Importance of Creativity in Engineering Design**

<table>
<thead>
<tr>
<th>High-Scoring Group</th>
<th>Low-Scoring Group</th>
<th>Faculty</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Always important during engineering design</td>
<td>• Important during design, but not always necessary</td>
<td>• Important part of engineering design</td>
</tr>
<tr>
<td>• Opens up design to more possibilities</td>
<td>• Engineers should not try to reinvent the wheel</td>
<td>• More important to have systematic design methodology</td>
</tr>
<tr>
<td>• Betters the engineering profession and society as a whole</td>
<td>• Creative engineers provide new ideas to stagnant companies</td>
<td></td>
</tr>
</tbody>
</table>

None of the students in either group felt that the mechanical engineering program developed their creativity. While each student in both groups believed their professors wanted them to be creative and valued creative thinking, they felt the program offered little to no opportunities to be creative beyond the basic freshman mousetrap design activity and the senior design project. The lack of development of creativity was primarily blamed on the lack of open-ended problems in nearly every
Moreover, when problems were open-ended, several students from both groups indicated they felt the problems were too constraint laden and relied more on synthesis of known procedures rather than allowing more divergent type thinking to take place.

Table 15

*Summary of Themes for Students’ and Faculties Perceptions of Creativity in the Mechanical Engineering Program*

<table>
<thead>
<tr>
<th>High-Scoring Group</th>
<th>Low-Scoring Group</th>
<th>Faculty</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Professors value creativity</td>
<td>• Professors value creativity</td>
<td>• Professors value creativity</td>
</tr>
<tr>
<td>• Limited opportunities to be creative</td>
<td>• Limited opportunities to be creative</td>
<td>• Creative thinking comes from knowledge of fundamentals</td>
</tr>
<tr>
<td>• Design problems too constraint laden</td>
<td>• Design problems too constraint laden</td>
<td>• Encourage creative thinking through discussion</td>
</tr>
<tr>
<td>• Development of creativity not schools primary job</td>
<td>• Development of creativity not schools primary job</td>
<td></td>
</tr>
</tbody>
</table>

While all faculty agreed they could be doing more in terms of developing creative-thinking skills, faculty believed an emphasis on obtaining the fundamentals should take precedent over developing creativity, and that ultimately, creativity comes through a knowledge of the fundamentals. Furthermore, eight out of the twelve faculty mentioned repeated attempts to get students to think creatively during lectures with example problems and scenarios designed to elicit creative thinking. The problem, as several faculty members indicated, is that if a student is not willing to open his or her mind up to what is being discussed and future possibilities, than it may be easy to miss the intention of problems given and/or discussions presented during lecture.
One interesting point of consensus among students of both groups as well as the faculty was that perhaps what is more important than the development of creativity is the development of sound problem solving methods, coupled with a knowledge of fundamental principles, such that students have the foundational skills necessary to think in a creative manner. Every student in both the high and low creativity groups agreed that while they feel the program did not adequately develop their creative thinking skills, they also believed that this was not the primary job of an engineering program.

Each student in both groups indicated that they believed it was not the professor’s job to teach creativity, rather they should teach the fundamentals, the science behind the design, and that it’s up to the student to then utilize this knowledge in a creative manner when necessary. Thus a dichotomy seemed to exist such that on one hand, students desired more opportunities to express creativity through more open-ended design projects and real world problem solving, and on the other hand they all agreed that an engineering program’s primary function is to develop the foundational skills in engineering science necessary for creative thinking.

**Summary**

This chapter described the findings from each of the four research questions that guided this study. A discussion of the test results from the Creative Engineering Design Assessment were described how the results allowed for the grouping of engineering students into high- and low-scoring groups were discussed. The perceptions of creativity
in engineering design among the high and low creativity groups were presented separately, and will subsequently be compared in chapter 5. Following the students perceptions, a synthesis of the perceptions of the mechanical engineering faculty pertaining to creativity in engineering design and the mechanical engineering program was presented. These perceptions will also be compared to those of the students in chapter 5 in order to assess any similarities and/or differences that may be present.
CHAPTER V

CONCLUSIONS AND IMPLICATIONS

Chance favors only the prepared mind.
—Louis Pasteur

“The principle goal of education is to create men who are capable of doing new things, not simply of repeating what other generations have done – men who are creative, inventive and discoverers”

The purpose of this study was fourfold. The first purpose was to measure the creativity of a sample of senior mechanical engineering students using an instrument called the Creative Engineering Design Assessment (CEDA). The CEDA was chosen because it allows for the measurement of students’ creative thinking skills specific to engineering design scenarios. The second purpose of this study was to identify engineering students’ perceptions of creativity during the engineering design process and compare perceptions of students who scored at the extreme ends of an instrument called the Creative Engineering Design Assessment. The third purpose of this study was to gather mechanical engineering faculty perceptions of creativity in the mechanical engineering program and its development of creative-thinking skills. The fourth purpose of this study was to compare students’ perceptions of the development of creative-thinking skills throughout the mechanical engineering curriculum to the perceptions of
mechanical engineering faculty to highlight similarities or differences between what
students perceived and what faculty members did in the classroom.

Perceptions, for this study, related to four primary themes: students’
perceptions of (a) the definition of creativity with respect to engineering design, (b) the
importance of creativity during engineering design, (c) the extent to which creativity
was developed throughout the engineering program, and (d) their own creative abilities.
In addition, mechanical engineering faculty perceptions were gathered to facilitate a
comparison between faculty and student perceptions of creativity in the mechanical
engineering program. The aforementioned perception data were obtained through
semi-structured interviews of students and questionnaire responses from the faculty.

This study used a mixed methods research design to identify themes related to
perceptions of creativity in engineering design that have the potential to influence
creative performance among engineering students. Although no causal inferences were
made from the thematic analysis undertaken during this study, the findings represent an
attempt toward understanding whether perceptions of creativity play a role in
influencing creative performance in engineering students. Consequently, this study
could serve to guide future research and classroom practices by identifying important
factors that may influence creative performance in engineering design.

Ultimately, this study was a step toward gaining an understanding of the role
creativity perceptions play in determining whether an individual is likely to engage in
creative thinking during the engineering design process. Thus, the results of this study
should interest engineering educators who may be looking for ways to encourage
creative thinking among their students, given the emphasis placed on creativity in engineering education by the National Academy of Engineering (NAE, 2004). Few researchers have explicitly asked engineering students about their perceptions regarding what it means to think creatively and whether the ability to think creatively is important during the engineering design process. An understanding of the value students place on creative thinking during the engineering design process is important considering the influence perceptions can have on students’ motivation to think creatively (Amabile, 1993, 1996; Baer, 1998; Ermanno & Saccetti, 2013). Comparing students’ perceptions of the engineering curriculum with the perceptions of engineering faculty provides an opportunity for faculty to assess the effectiveness of their instructional strategies.

This chapter consists of two sections. The first section provides the conclusions for each research question drawn from the results of the study discussed in Chapter IV. The second section includes implications of this study for practicing engineering educators as well as opportunities for future researchers looking to understand and investigate further the relationship between engineering students’ perceptions of creativity and their creative performances.

**Research Questions**

This research was guided by four research questions:

1. How creative are senior mechanical engineering students, as measured by the Creative Engineering Design Assessment?
2. How do perceptions of creativity in engineering design compare between senior mechanical engineering students with high and low divergent-thinking scores as measured by the Creative Engineering Design Assessment?
   
a. How do students define creativity with respect to engineering design?
   
b. What are students’ perceptions of the importance of creativity during engineering design?
   
c. What are students’ perceptions of creativity in the mechanical engineering program?
   
d. What are students’ perceptions of their own creative ability?

3. What are the perceptions among mechanical engineering faculty of creativity in the mechanical engineering program and its development of creative-thinking skills?

4. How do senior mechanical engineering students’ perceptions of the mechanical engineering program and its development of creative-thinking skills compare to the perceptions of mechanical engineering faculty?

Conclusions for Each Research Question

This section is a summary of the conclusions drawn from each of the research questions that guided this study.

Research Question 1: Students’ Performance on the Creative Engineering Design Assessment

The wide range in total scores collected from the Creative Engineering Design Assessment (CEDA), ranging from a low of 42 to a high of 207, coupled with a large standard deviation of 39.37, indicated a wide variation in creative performances among the 42 senior mechanical engineering students tested for this study. In comparison with the freshman engineering students who took the CEDA during the initial development of the instrument (n = 52), the authors noted a higher overall mean score of 127.40, but
this was accompanied by a higher standard deviation 65.32 than what was noted in this study (Charyton, 2008, 2014). This particular instrument has never been administered to senior engineering students from any engineering discipline prior to this study, thus no comparisons to other studies can be made. However, the mean score obtained by participants of this study (M = 100.26) are consistent with scores obtained by senior engineering students taking similar creativity assessments including the Owens Creativity Test and the Purdue Creativity Test (Charyton et al., 2008, 2009, 2011; Rouyendegh, 2011). Both the Owens Creativity Test and the Purdue Creativity Test are no longer in use and have been replaced by the CEDA.

The large standard deviation obtained by students in this study allowed easier selection of students with extreme scores (3 standard deviations away from the mean for the high-scoring group and 2 standard deviations away from the mean for the low-scoring group). The extreme-scores approach has been used previously in quantitative studies as a means to increase statistical power to detect an effect (Bernichon, Cook, & Brown, 2003; Cross, Morris, & Gore, 2002; Holland, 2002). Along these lines, groups representing the extreme scores were chosen for comparison in this study in order to more readily discern differences in perceptions of creativity between high- and low-scoring groups as measured by the Creative Engineering Design Assessment (CEDA). However, given that perception data were collected from students who represented these extreme scores, the generalizability of any conclusions drawn from the findings to students in other settings may be limited. These students’ perceptions may not reflect the perceptions of participants who scored closer to the mean.
Research Question 2: Students’ Perceptions of Creativity in Engineering Design

Conclusions from students’ definition of creativity with respect to engineering design. Both the high- and low-scoring groups described a creative engineering design in terms of levels of creativity: A completely original design was the highest level of creativity. Creativity that resulted from incremental modifications to an existing product or process was equally important in engineering design, but rated lower on the creativity scale. This suggests that students from both groups have a differentiated view of creativity and that this differentiated view was across all students from both groups and therefore had no effect on creative performance with respect to this sample of students. This differentiated view of creativity has been found in studies investigating laypersons conceptions of creativity (Kaufman et al., 2010; Kaufman & Beghetto, 2009) and is similar to the distinction conceptualized by Howard Gardner. For example, Gardner (1993) conceptualized two levels of creativity: “little C” creativity and “big C” creativity. Little C creativity is the kind of creativity that people exhibit frequently in daily life, and big C creativity is that kind of creativity that results in historical breakthroughs that occur only very occasionally (Gardner, 1993; Renzulli & Gardner, 1993).

The recognition of creativity as more than simply creating something that has never existed before is particularly useful to the student because it allows creativity to be seen on a practical level as a tool that can aid in everyday problem solving. As Snider et al. (2013) indicated, creativity occurs in the act of using new knowledge or old knowledge in a new way. Although a popular view of creativity may be linked to
imagination or the ability to develop novel and original ideas, positioning creativity as expanding or broadening existing ideas demonstrates its applicability beyond conceptual design. For example, in engineering design, engineering creativity could be linked to identifying a brand new design to solve a problem, but it could also be linked to identifying new materials, making cost reductions, or achieving weight savings with an existing design as well. Such a realization allows creativity to be viewed as a practical tool useful not only for generating ideas during design but also for routine problem solving in professional and personal life.

All students from both groups acknowledged that creative people always seemed to have a high degree of both foundational knowledge and prior experiences with the problem they were investigating. All students from each group stated they believed that not only was this type of knowledge common to all creative people, but they also felt it was central to being able to think creatively. These perceptions are consistent with what psychologists have called declarative knowledge and procedural knowledge, both of which are necessary for creative problem solving (Fasko, 2001; Runco, 1996; Runco & Chand, 1995; Zhou, 2012). Declarative knowledge is knowledge gained by study, and procedural knowledge represents knowledge obtained via prior experience working with the problem (Feldhusen, 2005; Mayer, 2005). Both types of knowledge are widely considered central to creative cognition (Runco & Chand, 1995; Runco, 2004; Zhou, 2012). Essentially, knowledge provides the source of creative ideas; thus, one cannot expect to think creatively about a problem without at least a modicum of knowledge about the domain in which the problem resides.
The origins of such beliefs are not difficult to imagine. Some of the most creative individuals in history have been known to have considerable expertise (large knowledge base) in their particular field, and therefore an association between creativity and knowledge can be considered an inevitable conclusion drawn by students. This finding suggests engineering students come to the classroom with at least a modicum of awareness of what is required to think creatively during the engineering design process. Moreover, given that students are aware that foundational knowledge and prior experience constitute a basic necessity for creative thinking, this suggests students conceptualize creativity as more than just a spark of insight from unknown origins, but students see creativity as involving cognitive aspects which are considerably more under ones control than a spark of insight leading to a creative idea.

Regarding the question of whether creativity is an inborn trait or a skill that can be developed, some students in each group believed creativity is a skill that can be developed if one works within or is otherwise exposed to a supportive environment that tolerates creative thinking. Other students within each group viewed creativity as an all-or-nothing type of skill; that is, either one has it or one does not. Two out of four students within both groups described the ability to think creatively in engineering design in terms of the latter, describing creativity as a “gift” or a “knack” for coming up with great ideas or insights that some have while others do not. Such dichotomous perceptions among members of both groups are congruent with the perceptions of other populations, for example, grade school teachers and students, higher education
faculty, and managers (Daly, Mosyjowski, & Seifert, 2014; Dym, Agogino, Eris, Frey, & Leifer, 2005; Tolbert & Daly, 2013; Zappe et al., 2013).

In the proceeding studies, researchers found that nearly half of the population sampled viewed creativity as an inborn all-or-nothing skill, whereas the other half of the population held beliefs that creativity is a pluralized, transdisciplinary, learnable, and teachable skill. The perception that creativity is an inborn trait is unfortunate because several studies have shown that the ability to think creatively is a skill learnable with practice (Kim & Coxon, 2013; Scott et al., 2004a, 2004b; Sternberg, 2007). However, given that such perceptions were present among students within both the high- and low-scoring groups, it is reasonable to conclude, at least for this study, that such perceptions had little effect on creative performance. Therefore, creative performance may not be dependent on one’s implicit beliefs about the nature of creativity and therefore may not affect students’ willingness to engage in or otherwise enhance their creativity.

Further, although half the students in both groups felt creativity was a skill that one either has or has not, all members of both groups held the perception that knowledge is an important component of creative thinking. This suggests all eight students interviewed believed that one is capable of coming up with creative solutions to a given problem if one possesses a certain amount of foundational knowledge about the problem. This conclusion has important implications for the engineering classroom, which is viewed as the primary conveyor of foundational knowledge, a domain-relevant skill necessary for creative thinking (Amabile, 1996, 2012). In other words, if students
believe that foundational knowledge can influence creative thinking, and if such beliefs are reinforced in the classroom by faculty, then students may be more likely to believe they are capable of creative thinking when encountering various engineering design situations, as long as they have relevant foundational knowledge.

Given the proceeding discussion, it can be concluded that all eight students from both groups held clear perceptions regarding how they define creativity in engineering design and what skills are necessary to be creative during the engineering design process. While the definitions students gave were far from complete in comparison with the literature, the aforementioned discussion does suggest that student’s come to the classroom with clear perceptions of creativity and these perceptions aligned well with currently accepted theories of creativity (Amabile, 1996; Gardner, 1993; Runco & Chand, 1995). This result is not surprising given that a recent study suggests most laypersons do hold implicit beliefs about what creativity is and what types of knowledge is necessary to produce something that would be considered creative to others (Kaufman & Beghetto, 2009a; O’Connor, 2012).

Creativity, despite its complexity and lack of a consistent definition in the literature, is a construct that is used in everyday language by many laypersons. As a result, most individuals have developed their own preconceived notion concerning what creativity is and what is required to produce something that would be considered creative to others (Runco, 1996, 2004, 2015). Furthermore, studies have shown that laypersons definition of creativity, while typically not complete, often incorporate many of the essential elements that most models of creativity include, similar to the results
found in this study (Amabile, 1996; Kaufman & Beghetto, 2009a; Runco & Chand, 1995). Hence, large differences in definitions of what creativity is were not expected among students from either group, and thus were not expected to influence engineering student’s creative performance. It is important to note however, that despite the conclusion that students definition of creativity in engineering design did not appear to influence their creative performance, having clear and accurate perceptions of what is required to be creative is important and provides a foundation for future creative performance (Cropley, 1999; Tolbert & Daly, 2013; Zappe et al., 2013).

**Conclusions from students’ perceptions of the importance of creativity in engineering design.** Each student in the high-scoring group perceived creativity to be an important and necessary component of engineering design. Each student repeatedly stated a belief that it was always important to be creative. Harold described it as “the X factor” that allows an engineer to move beyond existing limits and push technologies in new and exciting directions.

When viewing the high-scoring group’s perceptions of the importance of creativity as a whole, it was clear that the group viewed creativity not only as producing a new and useful design, but also as a holistic, global phenomenon. In other words, the high-scoring group saw creativity as a way of thinking that could be used not only to push technology further in design situations, but also to solve any type of problem, whether personal or professional, hence, their rationale for believing one should always strive to think creatively. This belief about creativity is encompassed in Richards et al.’s (1988) well-established theory of everyday creativity. This theory represents an inclusive
perspective of creativity founded on the belief that everybody is capable of being 
creative and that individuals should realize this creativity and apply it to all situations. 
The high creativity group clearly viewed creativity as more than simply being embodied 
within a particular product but viewed it in terms of what Nichols (1972) called 
“creativity as a normally distributed trait”.

Each member of the low-scoring group held perceptions similar to those of the 
high-scoring group with respect to the importance of creativity in engineering design. 
However, in contrast to the high-scoring group, each member of the low-scoring group 
emphasized a belief that creativity is not always necessary in engineering design, 
despite its importance. For example, three of the four students within the low-scoring 
group stated that following a logical and systematic procedure while designing is often 
more important than having a creative mindset.

Ultimately, each student in the low-scoring group emphasized that although 
creativity is important, engineers should also “not try to reinvent the wheel.” Every 
student in the low-scoring group mentioned this idea at least once; no one in the high-
scoring group mentioned it at all. Clearly, the low creativity group preferred to stay 
“within the box”—expand the box, perhaps, but stay within it nonetheless, while the 
high-scoring group clearly preferred original, outside-of-the-box thinking when engaging 
in engineering design.

These findings suggest that engineering students who are characterized as 
having high creative ability may tend to value creative thinking as an important part of 
engineering design and problem solving more so than their less creative counterparts.
Furthermore, these findings reinforce predictions made by the expectancy-value theory which posits that an individual’s choice, persistence, and performance can be partially explained by the value one places on a particular activity (Wigfield & Eccles, 2000). The high creativity group clearly valued creative thinking throughout the engineering design process more so than the low creativity group, and hence this theory suggests they were more motivated to be creative.

In terms of why the high creativity group valued creativity more so than the low creativity group, a possible explanation resides in the creative personality. Individuals who are categorized as creative tend to have personalities that are conducive to creative thinking such as openness to new experiences and ideas, thinking outside of the box, and always looking for ways to improve upon an existing product or process (Barron & Harrington, 1981; Cropley & Cropley, 2000; Runco, 2004). These personality characteristics are in contrast with less creative individuals that typically favor feasibility, functionality and simplistic designs over risky, unproven ones (Cropley, 1999; Kazerounian & Foley, 2007; Daly et al., 2014. This does not imply that individuals who do not have personality characteristics commonly associated with creative individuals cannot develop the skills necessary to be creative, indeed creativity has been shown to be a skill that can be developed (Cropley, 2015, Runco, 2015). It merely implies that students who do not possess creative personality characteristics tend to focus on convergent thinking rather than divergent thinking during the engineering design process, in other words, rather than coming up with multiple solutions to a given
problem; they try to find the one best solution that solves the problem, which is often
the simplest one.

Convergent thinking often involves a logical and systematic approach to
engineering design, which explains why this was a clear theme that originated from the
low creativity group. Unfortunately, logic and systematic approaches are often viewed
as counterproductive to divergent thinking and the production of novelty. That is not to
say convergent thinking is necessarily a bad thing; indeed convergent thinking is useful
during any type of analysis activity where one is focused on selecting the one best
solution to the problem, and is therefore an important element of creative thinking. The
problem is when convergent thinking is overemphasized at the expense of divergent
thinking which is contraindicative for creative thinking in the engineering classroom
(Cropley, 2015; Dym et al., 2005; Fasko, 2000-2001; Runco & Jaeger, 2012).

Unfortunately, unless specifically told to be creative, research suggests many
engineers are skeptical of any innovative idea not tied to an extant solution and
therefore tend to stay with safer, more traditional designs (Cropley, 2015; D. H. Cropley
& Cropley, 2000; Daly et al., 2014; Kazerounian & Foley, 2007). While this type of
thinking can certainly improve efficiency and the likelihood of developing a design that
at least “works,” it often limits an individual’s willingness to consider new approaches
and perspectives. This study suggests that while this may be true of certain engineers,
highly creative engineers appear to be more open to new design ideas and a willingness
to explore new solutions to old problems.
Conclusions from students’ perceptions of creativity in the mechanical engineering classroom. None of the students in either group felt that the mechanical engineering program developed their creativity skills. Although all students in both groups believed their professors wanted them to be creative and valued creative thinking, findings of this study suggest students perceive little to no opportunities to be creative beyond the basic freshman mousetrap design activity and the senior design project. The lack of development of creativity was primarily blamed on the lack of open-ended problems given in nearly every class. Moreover, when problems were open-ended, all students from both groups indicated they felt the problems were too constraint-laden and required more of a synthesis of known procedures rather than allowing more divergent thinking to take place.

These findings show that misconceptions exist about the relationship between engineering design, constraints, and creativity. The overall perception among students interviewed in both the high- and low-scoring groups was that too many constraints imposed upon students during design projects tended to limit students’ ability to think creatively, design outside of the box, and come up with solutions outside of the norm. This perception was misguided, however, as engineering is by definition design under constraint (Eckert, Stacey, Wyatt, & Garthwaitea, 2012; Goncher, 2009); thus, requiring a design project to be given with no constraints is simply unrealistic and offers little instructive value.

One possible origin of such a misconception involves the common association students have between creativity and design, that is, in order to come up with a creative
design, one needs unfettered restrictions to allow for the free flowing of ideas. This misguided association has been noted from both engineering students as well as professional engineers in studies investigating perceptions regarding the relationship between constraints and creativity in engineering design (Eckert et al., 2012; Goncher, 2009; Onarheim, 2012). Thus the perception that constraints can actually drive the creative process was not evident among students from either the high or low creativity groups.

However, the CEDA included multiple constraints for each design scenario in an effort to accurately mimic the engineering design process. These constraints did not appear to affect the high-scoring groups ability to generate multiple solutions to the given design scenarios, whereas the low-scoring group clearly had difficulty generating ideas as evidenced by the low fluency scores for each member of the low-scoring group. This suggests that while fundamental misconceptions did exist among all eight students regarding constraints and creativity in engineering design, students with a high degree of creativity were able to overcome the perceived constraint barriers and produce creative designs.

Conclusions from students’ self-perceptions of their creative abilities. It is clear that in terms of creative self-perceptions, the high-scoring group felt more confident in their abilities when it came to creative engineering design. When asked about their perceptions concerning their own creative abilities, each student in the high-scoring group emphatically stated they believed they were creative and had always held this belief about themselves. The low-scoring group clearly had different perceptions when
it came to assessing their own creative abilities. Two out of the four members of the low-scoring group felt they were not creative when it came to engineering design. The remaining two members felt they possessed the ability to think creatively but it was often a struggle to get it come through.

Thus, the placement of these students in their respective groups aligns with the predictions of the expectancy-value theory. The expectancy-value theory posits that a students’ performance in a given situation is related to their expectations of doing well, which is directly related to the degree to which they are confident in their abilities in the given situation (Eccles & Wigfield, 1992, 2000, 2002). The high-scoring group expected to do well on a creativity task, given their self-perceptions as creative individuals, and hence they did perform well. Similarly, the low-scoring group perceived themselves as being not very creative, and hence, their performance on the test reinforced their self-perceptions.

It is important to note that, although the number of students interviewed for this study was small (n = 8) and thus prohibits any large-scale generalizations, this study is aligned with the findings from other researchers who have suggested an individual’s self-perception of his or her creative abilities could have an effect on his or her creative performance (Chua & Iyengar, 2008; Genco, Holtta-Otto, & Seepersad, 2012; Gralewski & Karwowski, 2012; Tierney & Farmer, 2002). This effect likely occurs because an individual’s perceptions concerning his or her ability to think creatively has a strong influence on motivation and ability to engage in creative thinking (Bandura, 1977; Diakidoy & Kanari, 1999) and to pursue creative tasks (Bandura, 1986). Bandura (1997)
cited creative self-perceptions or a belief in one’s ability to engage in creative
endeavors, as a necessary condition for creative productivity and the discovery of "new
knowledge" (p. 14).

It is important to note that while it is common for some engineering students to
hold the perception that they are not creative people (Kazerounian & Foley, 2007), this
belief does not mean that they cannot be taught to act creatively (Scott, Leritz, &
Mumford, 2004). Creativity is not an attribute or ability that one either has or does not
have (Kirton, 2003); rather, all individuals are capable of exhibiting it in different ways,
at different levels, and in differing times and circumstances (Cropley, 2001; Sternberg &
Lubart, 1995; Treffinger et al., 2002). Students’ creative skills can be developed and
fostered, just as practice in any specialized domain can lead to improvements in skills
(Ericsson, Krampe, & Tesch-Romer, 1993). A university course can improve students’
creative skills by aligning course content, instruction, assessments, and the environment
towards creativity focused learning goals.

**Research Question 3: Perceptions of Creativity among Mechanical Engineering Faculty**

Eight of the twelve faculty members admitted that they should be doing more in
terms of providing more opportunities for students to develop their creativity through
open-ended design projects. This suggests faculty do value creativity in engineering
design. However, an overarching theme from faculty responses was that developing a
systematic and logical approach to problem solving, coupled with a firm grounding in
the fundamentals of engineering science was perhaps more important than developing
creative thinking skills. This suggests faculty may tend to value convergent thinking more so than creative thinking with respect to engineering design.

Evidence for this conclusion stems from the repeated usage of terms such as systematic and logical when it comes to problem solving methodologies, which are often viewed as counterproductive to creative thinking (Runco, 2015). This valuing of declarative knowledge (i.e. factual knowledge) over other types of skills is a common occurrence among many faculty from a variety of disciplines (Amabile, 2012; Daly et al., 2014; Runco & Chand, 1995). This is likely because the typical engineering faculty member has amassed a considerable amount of fundamental knowledge throughout their formal education in very structured engineering programs, in which scientific and mathematical accuracy was likely valued over creativity (Cropley & Cropley, 2000, 2009; Cropley, 2015; Daly et al., 2013, 2014). Thus faculty may tend to value declarative knowledge over other types of knowledge, and is therefore what is emphasized in their classroom.

Research Question 4: Comparison of Students’ and Faculty Members’ Perceptions of the Engineering Program

It was discussed in the conclusions for research question two that none of the students in either group felt that the mechanical engineering program developed their creativity. While each student in both groups believed their professors wanted them to be creative and valued creative thinking, they felt the program offered little to no opportunities to be creative. The lack of development of creativity was primarily blamed on the lack of open-ended design problems throughout the curriculum.
In terms of the perceived lack of opportunities to develop their creativity throughout the ME program, eight out of the twelve faculty members interviewed claimed just the opposite however. These faculty members stated that while they felt they could be doing more in terms of giving students opportunities to work on realistic design problems, they also claimed they routinely attempt to force students to think outside of the bounds of existing limits and think divergently about problems during lectures. This finding suggests clear differences exist between what faculty are doing in the classroom to promote creative thinking and what students perceive.

Thus it is reasonable to conclude that students do not perceive that the goal of such discussions are to think outside of existing solutions and develop novel ideas or solutions to problems discussed in class, as faculty have suggested is their intent. Furthermore, faculty are likely not being explicitly clear on the goal or intent of the exercise, a necessary prerequisite for getting students to think creatively during activities or discussion where the goal of such activities or discussions is to stimulate creative-thinking (Runco, Illes & Eisenman, 2005). Given that both the high- and low-scoring groups perceived a lack of opportunities to develop their creativity throughout the ME program, this perception did not appear to have any significant influence on creative performance. Furthermore, while faculty claimed they do attempt to integrate creative thinking into their lectures and apply more student-centered instructional strategies, it is clear that students feel it is not enough.

It is important to note however, that prior studies have shown that very often a dichotomy exists between what the student’s desire in terms of more open-ended
problems and the backlash that results when such a student-centered approach to learning is implemented. In particular, several studies have documented the resistance exhibited by students when open-ended design problems are assigned (Felder, 1994, 1995, 2012), and this might provide an explanation as to why many instructors tend to employ more traditional, teacher-centered instructional strategies. As Richard Felder explains (2012),

Instructors who set out to try student-centered instruction in a class for the first time are often unpleasantly surprised by the fierce negativity of some responses. Many who don't anticipate such reactions get discouraged when they encounter them, give up, and go back to more comfortable but less effective methods. (p. 4)

**Implications and Suggestions for Future Research**

This study generated new insights regarding the relationship between student and faculty perceptions of creativity in engineering design and creative performance. The following are some implications that may be useful for engineering educators as well as for guiding future researchers in the areas of engineering education and engineering creativity.

**Implications for Creativity and Engineering Design in the Mechanical Engineering Program**

All eight of the mechanical engineering students interviewed for this study felt the mechanical engineering program lacked an emphasis on developing creative-thinking skills. Moreover, it was equally clear that students viewed design projects whose goal was to elicit creative thinking and design projects whose goal was to emulate real-world engineering design as being mutually exclusive. That is, several
students felt that design projects aimed at encouraging creative thinking should be completely open-ended, with no constraints, for example, projects that gave students an end goal, with no limitations in terms of physical dimensions, weight, materials, capacities, or motion. This scenario is obviously contrary to design projects students are likely to encounter in industrial settings and thus revealed a misconception about the relationship between engineering design, constraints, and creativity.

Engineering design is frequently recognized as a constraint-intensive domain (Ajit et al., 2008; Stacey and Eckert, 2010). Although the term constraints often implies unpleasant restrictions on free will and creativity (Amabile, 1982; Stokes, 2005, 2008), numerous authors have pointed out that without constraints there can be no creativity (Dyer et al., 2009; Johnson-Laird, 1988; Joyce, 2009; Rosenman & Gero, 1993; Stokes, 2005). Not only can constraints enhance creativity, but they are often viewed as a prerequisite for all creative activities (Horowitz & Maimon, 1997), even with regard to artistic creativity, although constraints placed on artists are typically self-imposed (Onarheim, 2012; Runco, 2015; Stokes, 2008). Some types of constraints can be highly limiting for creativity (Salter & Gann 2003), but without constraints, there can be no problem to solve and thus no potential for creativity (Cropley, 2000, 2015). Engineering creativity is about finding ways to circumvent the constraints, to push the boundary of the available design space outward by exploring new possibilities, challenging norms, and taking calculated risks (Eckert et al., 2012). Moykr (1990) stated, “Technological change involves an attack by an individual on a constraint that everyone else takes as a given” (p. 9).
Therefore, an important implication of this finding for faculty is to emphasize clearly that engineering design under constraints does not limit creativity, but can be a boon to it. Further, explicit instructions to be creative during design exercises can have a significant impact on students’ creative performance (Runco, 2005; Silvia, Winterstein, et al., 2008; Yilmaz, Seifert, & Gonzalez, 2010) and should be used whenever design is integrated into the classroom. This not only forces students to practice looking for unobvious solutions to problems when confronted with multiple constraints, but also reinforces the notion that value is placed on creative thinking during the engineering design process. Such an emphasis should be an objective for any engineering course that integrates design into its requirements.

The findings of this study also suggest a disconnect exists between what faculty are doing in the classroom to encourage creativity and what engineering students perceive faculty are doing. The perceptions of the students interviewed were clear: Little opportunity was given for creativity throughout the mechanical engineering program. Students emphasized an overabundance of closed-ended problems with a single correct solution rather than open-ended design problems. Dym et al. (2005) described this approach to learning as an epistemological approach involving systematic questioning, wherein known, proven principles are applied to analyze a problem to reach verifiable, “truthful” (p. 2) answers or solutions. While such problems may be sufficient for developing a future engineers problem solving and analysis skills, they are not sufficient for developing innovative thinking (Kazerounian & Foley, 2007).
The faculty felt differently however: They claimed they emphasized creativity in the classroom, if not with open-ended design projects, then with discussions and the posing of questions concerning future challenges and opportunities. Thus, it is reasonable to conclude that open-ended projects, activities, and classroom discussions intended to encourage students to think outside of the box were often not recognized by students as such.

This finding leads to the implication that faculty can actively promote creative thinking by being explicit about the intentions of assigned design projects and classroom discussions. In particular, when faculty engage in discussions with the purpose of encouraging students to think divergently, it should be made explicitly clear to the students that such topics are purposefully intended to motivate students to think about possible creative solutions to current and future engineering problems. In this way, students gain practice in what is known as “reflective thinking”, which involves defining a problem, come up with potential solutions to it, and then evaluating and revising accordingly. These three elements which comprise reflective thinking are often referred to as metacognitive strategies, which can be very helpful for developing creative thinking skills (Hargrove & Nietfeld, 2014; A. J. Cropley, 1999; Daly et al., 2014; Kaufman, 2012). This can only work however, if students are willing to engage in the exercise, and faculty makes it explicitly known the intent of the exercise.

A perceived lack of engineering design opportunities was also a noted grievance among all students from both the high- and low-scoring groups. Students felt that having few design opportunities minimized their chances to practice what they would
be doing in the private sector and limited their opportunities to develop creative-thinking skills. Thus, an important implication of these findings is that students should be engaged in design activities from the beginning of their engineering programs. Several studies have indicated that an important influence on students’ ability to develop creative-thinking skills comes from experience in engineering design within a variety of different problem contexts (Crismond & Adams, 2012; Cross, 2004; Yilmaz & Siefert, 2011). In other words, creativity is heavily influenced by experience (Runco, 2004; Runco & Chand, 1995; Zappe, 2013; Zappe et al., 2013). For example, in freshman and sophomore engineering courses, students should be engaged in small, well-defined design problems that can be accomplished in a short time (i.e., two to three weeks).

While it may be that the fundamental purpose of an engineering education is to develop logical and rationale problem solving skills, or convergent inquiry skills, given that many students will be expected to engage in engineering design sometime in their careers, students should be trained not just in convergent analysis but in divergent inquiry as well throughout their academic careers. While it is clear that several faculty members do attempt to engage in divergent inquiry via reflective thinking during lecture, students also need opportunities to develop their divergent inquiry skills while working on actual design projects, similar to those they will encounter in engineering practice.

Moreover, such design problems should make use of knowledge learned in other courses to enhance integration of subject matter throughout the curriculum. In typical engineering programs, material taught in a given course is often treated as separate and
distinct from all other courses, and it is not until a senior capstone design project that students are given an opportunity to integrate the subject matter learned in previous courses (Froyd & Ohland, 2005; Heywood, 2005; Neely, Sheppard, & Leifer, 2006). However, if design projects were required in multiple courses throughout all four years of the traditional engineering curriculum, students could develop creative-thinking skills through real-world design experiences that integrate the subject matter and material learned up to that point.

Ultimately, because engineering design necessarily involves a dynamic interplay between convergent and divergent inquiry, opportunities to practice both and be assessed in terms of both should be included in an engineering student’s education (Dym et al., 2005; Eris, 2006). However, it is important to recognize the inherent difficulty that comes with attempts to objectively assess student’s design work. Such difficulties stem from the complex nature of the engineering design process itself (Davis et al., 2011) and may account for why many engineering faculty do not readily assign such projects in their classes. This is because divergent inquiry involves answers to questions that do not necessarily have an associated truth value, that is, they are not necessarily verifiable (Jaarsveld, Lachmann, & Leeuwen, 2012; Vere, 2009; Zappe et al., 2013). This often seems to conflict with the principles and values that are at the core of the predominantly deterministic, engineering science approach to engineering education.

Objectively evaluating student design work in terms of subjective elements such as creativity is not unlike evaluating divergent thinking tests, however. Divergent
thinking tests typically invoke a panel of judges or raters to evaluate student work, with the judging panel being comprised of any individual with considerable knowledge in the domain in question. The central idea behind such an evaluation technique is that experts within a given domain are likely to agree on criteria such as originality and usefulness of a given design (Hennessey, Amabile, & Mueller, 2011). Such an assessment method could be valuable in assessing student design work throughout the engineering curriculum. Through collaboration with multiple faculty members who bring their own subject-matter expertise, as well as the identification of specific outcomes for each design project, it is possible to evaluate open-ended design projects objectively while also limiting the subjective bias that inevitably arises with a single human evaluator.

Implications for Future Research

It was clear from the students’ interviews that there were differences among the high- and low-scoring groups in terms of their perceptions about the importance of creativity in the engineering design process. Creativity was an important component of engineering design for both groups; however, it was perceived as more important by the high-scoring group. These findings indicated engineering students who are characterized as having high creative ability may tend to value creative thinking as an important part of engineering design and problem solving more so than their less creative counterparts.

This difference indicates a potential relationship between creative performance and perceptions of the importance of creativity in the engineering design process. In addition to reinforcing outcomes predicted by the expectancy-value theory, it also has important implications for the engineering classroom given the malleability of an
individual’s perceptions (O’Connor et al., 2012; Tierney & Farmer, 2002). In other words, unlike personality traits, which are relatively stable across time, perceptions about a construct such as creativity can vary depending upon context, motivation, attitudes, values, affect, and even environment (Pickens, 2005; Runco, 2015). Therefore, engineering educators should encourage students to think creatively and provide opportunities for them to do so in the hope that students may begin to see value in this type of thinking and thus recognize the importance of creative thinking during engineering design and problem solving. However, faculty must provide an atmosphere that supports and encourages creative thinking if students are to see value in it. Such an atmosphere can relay to students that not only is creative thinking an important skill to develop, but that engineering educators also value it, and therefore the likelihood of students perceiving creativity as important during the engineering design process also increases (Cropley, 2015; Runco, 2015).

Further, differences were found between the high- and low-scoring groups in terms of their creative self-perceptions, indicating a potential relationship between creative performance and students’ creative self-perceptions. The high-scoring group clearly envisioned themselves as being naturally creative and felt confident in their creative abilities, especially in solving mechanical problems such as the ones most often encountered in mechanical engineering practice. The low-scoring group, in contrast, clearly felt less confident in this area; two individuals felt they lacked such abilities altogether. Such findings show that creative self-perceptions may be an important and necessary condition for creative productivity (Bandura, 1997).
Runco (2004, 2015) and Beghetto (2006) emphasized the importance of what is referred to as *extra-cognitive skills* such as self-perception as being just as important to creative performance as traditional attributes such as personality, motivation, and intelligence. Positive creative self-perceptions can support a student’s self-confidence in his or her creative abilities and help support a student’s resistance to conformity with respect to his or her thinking and ability to stand up for his or her own ideas (Beghetto, 2006; Diakidoy & Kanari, 1999; Runco, 2015). All of these traits are typical attributes commonly ascribed to creative individuals (Beghetto, 2006; Runco, 1996, 2004, 2015).

Although a student’s self-perception of his or her own creative ability may seem like an attribute that is beyond the control of anyone aside from the student, this appears not to be the case. Beghetto (2006) and Penga et al. (2013) showed that teachers and the classroom environment itself have the potential to influence students’ creative self-perceptions via encouragement to be creative on assignments, opportunities to be creative through open-ended projects that encourage teamwork, brainstorming opportunities, and recognition and evaluation of creativity in various learning situations.

It is important to recognize that the relationships found in this study were based on a limited number of participants; therefore, the results are not generalizable to a larger population. Nevertheless, the results previously described involving creative performance, perceptions of importance of creativity, and students’ creative self-perceptions indicate that relationships between these elements may exist. Therefore, more research is needed to investigate these potential relationships, perhaps using
quantitative measures to assess perceptions of importance of creativity and creative self-perceptions, in order to discern whether these perceptions represent significant factors in predicting creative performance, particularly in an engineering design context.

Moreover, duplicating this study with a larger number of participants and with students from different engineering fields may yield different results from those observed in this study. A comparison of perceptions with respect to gender and how such differences may impact creative performance in engineering design represents another avenue of research that can be extended from this present study. While there is no evidence of gender differences in creativity using traditional creativity tests, Simonton (1994) gives several examples of observed real world differences in creativity between men and women. This suggests a need for a study that investigates domain specific creativity differences between men and women, in particular, within the domain of engineering. Moreover, such a study could follow up on the test score results with interviews of participants from both genders and attempt to interpret differences in creativity scores through not only an examination of individual differences among the participants, but also through any sociocultural differences that may exist as well.

Further, although perceptions of importance and creative self-perceptions may influence creative performance, it is unlikely that there is a direct causal link between them. Creative performance is heavily influenced by factors such as level of motivation, personality factors, environmental considerations, and many others (Runco, 1995, 1996, 2004; Cropley, 2015). Therefore, additional research is needed to assess how perceptions of importance and creative self-perceptions interact with other variables.
known to influence creative performance. Researchers could seek to determine if a direct causal link exists or if these perceptions mediate the effects of other variables. Further research could guide subsequent inquiry and theory development within creativity research.

Summary

This chapter provided the conclusions and resulting implications produced by a study of the perceptions of creativity among engineering students who scored at the extreme ends as measured by a divergent-thinking test. Further, students’ perceptions of the development of creative-thinking skills throughout the mechanical engineering curriculum were compared to those of mechanical engineering faculty to highlight any differences between what students perceived and what faculty did in the classroom. Such comparisons were intended to provide a basis for the development of a better understanding of how perceptions of creativity may influence students’ creative performance outcomes. In addition, the investigation of differences between students and faculty in terms of creativity in the mechanical engineering program may help educators understand where differences in perception may exist, as well as locate opportunities to improve upon students’ learning experiences.

Several important implications were noted. First, the findings of this study aligned with the predictions of the expectancy-value theory. In particular, in the context of the theory, I predicted that those students who valued creativity in engineering design and confidently believed they had the ability to be creative were more likely to be creative in various design scenarios. More research, particularly involving
quantitative measures and larger populations, is needed to determine if such findings are significant.

In addition, students’ perceptions that design constraints led to fewer opportunities to be creative in engineering design was a misconception that needs to be remedied. Engineering is by definition design under constraint; however, such constraints should not limit creativity but provide more opportunities to be creative. Therefore, an important implication is that faculty should clearly emphasize that engineering design is design under constraint, and such constraints provide engineers the opportunity to be creative. A disconnect appeared between what faculty did to encourage creative thinking in the classroom and students’ perceptions of those practices, which indicates more explicit instruction is needed by faculty on the benefits of creative thinking in engineering design.
REFERENCES


Goldenberg, J., & Mazursky, D. (2000). First we throw dust in the air, then we claim we can’t see: Navigating in the creativity storm. *Creativity and Innovation Management, 9*(2), 131–143.


APPENDIX A

CREATIVE ENGINEERING DESIGN ASSESSMENT AND INSTRUCTIONS

2.12 CEDA

Before beginning, please provide the following 3 pieces of identification:
  Course number ______ Semester/Quarter: ______
  Assigned Student Number ______________________
CEDA: Creative Engineering Design Assessment.

At the top of the following, each page is a set of 2, 3, or 4 three-dimensional figures. Please use one or more of these figures to generate two original designs that will accomplish the general goal written below them. You can imagine that the figures are made of any material you wish and can be any size that you wish for each design. They can be solid or hollow and can be manipulated in any manner you wish. You may combine the figures on each page and may draw additional elements as required by your design. However, each figure can only be used once per design. On each page, be sure to:

1. Sketch your designs.
2. Label each design (provide a brief description—what is your design?).
3. Describe your materials.
4. Identify additional problems that your design may solve.
5. Identify the users (specific persons) of each design.

Total time for this assessment is 30 min for 3 pages, or about 10 min per page. You may use your time as you see fit. Two designs should be created per page. Additionally, at least one response should be indicated for each of the boxes below your sketch for each design. You may use a pen or pencil, whichever you prefer.

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<thead>
<tr>
<th>Sketch</th>
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<tr>
<td>Description (What is your design?)</td>
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<tr>
<td>Describe the Materials</td>
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<td>Additional Problems solved</td>
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<td>Users (persons that could use your design)</td>
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APPENDIX B

INTERVIEW PROTOCOL

Introduction – Thank you for taking the time to speak with me today. I would like to learn more about your perceptions of creativity as it pertains to the engineering design process as well as the engineering program.

Theme # 1: Definition of Creativity

a. What does engineering design mean to you? What does it necessarily involve?

b. What would you consider a creative engineering design? What characteristics make it creative?

c. When you think about someone whom you consider really creative, what characteristics do they have? What sets them apart from others?

d. Do you think a creative person is born creative, or is it possible to become creative if you work at it? Explain.

Theme # 2: Importance of Creativity in Engineering Design

a. Do you think it is important to be creative while engaging in engineering design? Explain.

b. Do you think creativity is important in the engineering profession? Explain.

Theme # 3: Perception of Creativity throughout Engineering Program

a. Do you feel you were encouraged to come up with multiple ways to solve given problems during your mechanical engineering classes? Explain.

b. Do you feel you were encouraged to spend time formulating the problem before coming up with a solution with sketches, written descriptions of the problem, etc.? Explain.

c. Do you feel you were encouraged to come up with multiple solutions to a given design problem? Explain
d. Do you feel you were encouraged to evaluate your solution to a given problem to verify that it solved the problem, made physical sense, was the most appropriate, etc.? Explain.

e. Do you feel the coursework you took in the mechanical engineering program provided opportunities for you to be creative? What more could they have done?

f. Do you feel the mechanical engineering program as a whole helped you to develop the ability to think creatively when working on design problems? Explain.

Theme #4: Self-Perception of Creative Abilities

a. Do you consider yourself to be a creative person? Explain.

b. Do you feel you are more creative in a particular area, or you tend to be creative in all areas?
APPENDIX C

MECHANICAL ENGINEERING FACULTY QUESTIONNAIRE

E-mail Heading: Creativity in the Mechanical Engineering Curriculum Questionnaire

Dear Professor,

Hello, my name is Wesley Carpenter and I am a doctoral student in the Department of Curricular and Instructional Studies at The University of Akron. I am currently conducting a research study to better understand the relationship between perceptions of creativity in engineering design and creative performance among senior mechanical engineering students. As a part of this study, I am looking to compare senior mechanical engineering students’ perceptions of creativity with respect to the mechanical engineering curriculum with those of faculty. Please take a moment to answer the following questions by simply typing your answer under each of the four questions below in a reply e-mail.

1. How do you define creativity with respect to the engineering design process?

2. Do you feel creativity is an important component of the engineering design process?

3. Do you feel the mechanical engineering curriculum at the University of Akron develops student’s ability to think creatively when working on engineering design problems? If yes, what aspects of the program do you feel contribute to the development of creative thinking? If no, what should the program be doing that it currently is not?

4. What do you do specifically in the classroom to encourage your students to think creatively when working on engineering design problems or engaged in engineering problem solving?

I sincerely thank you for your participation!

Sincerely,

Wesley Carpenter
Doctoral Student
Department of Curricular and Instructional Studies
The University of Akron
wac1@uakron.edu
Hello, my name is Wesley Carpenter and I am a doctoral student in the Department of Curricular and Instructional Studies, at The University of Akron. I am currently conducting a research study to better understand the relationship between perceptions of creativity in engineering design and creative performance among senior mechanical engineering students. To accomplish this, I am inviting you to participate in my study which will require you to take a creative engineering design assessment which will last exactly 30 minutes. It involves three engineering design scenarios, and you will have 10 minutes per scenario to design as many different solutions to the given scenario as possible. In addition to helping me complete my research, this will be an opportunity to test your design capabilities under various constraints, in effect, to see how well you can design under pressure. It could be a great learning experience for you!

If you decide to participate, you may also be selected for follow-up interviews if your completed test happens to be selected. If selected for an interview, I will be sending you an e-mail to select a day and time that are most convenient for you.

Note: For those students who decide to participate, I will then hand out a packet containing the following materials:

1. The informed consent letter detailing all relevant information necessary for participation in the study
2. A demographics Questionnaire
3. The Creative Engineering Design Assessment (CEDA)
4. Once the packets have been handed out, I will then proceed to instruct the students to carefully read the instructions provided on the cover sheet of the CEDA.
Title of Investigation: Engineering Creativity: Toward an Understanding of the Relationship between Perceptions and Performance in Engineering Design

Name of Principal Investigator: Wesley Carpenter

1. This research project is being conducted by Wesley Carpenter, a doctoral student in the Department of Curricular and Instructional Studies at The University of Akron.

2. The purpose of the research study is to explore how perceptions of creativity vary among individuals with different creative abilities as measured by a divergent thinking tests specific to the domain of engineering.

3. There are no risks associated with this study.

4. Participation in this research project is voluntary and not a requirement or a condition for being the recipient of benefits or services from the University of Akron or any other organization sponsoring the research project.

5. The data collection will be completed without use of names to keep the individual participants from being identified. The signed consent form will be kept separate from the data so no one will be able to link their responses to the form.
6. If you decide to participate in this study you will be asked to:

- Complete a demographics questionnaire
- Complete a creative engineering design assessment (CEDA)

7. The creative engineering design assessment will last exactly 30 minutes and will consist of three engineering design scenarios. You will have 10 minutes per scenario to design as many different solutions to the given scenario as possible.

8. Upon evaluation of the assessment, you may be selected for a follow-up interview(s). If selected for an interview, I will send you an e-mail to select a day and time that are most convenient for you.

I have read the information provided above and all of my questions have been answered. I voluntarily agree to participate in this study. I will receive a copy of this consent form for my information.

__________________________________ ________________
Participant Signature Date

If you have any questions about this research project, you can contact Wesley Carpenter at wac1@uakron.edu. This research project has been reviewed and approved by The University of Akron Institutional Review Board for the Protection of Human Subjects. Questions about your rights as a research participant can be directed to the Institutional Review Board at 1-330-972-7666.

Thank you for your participation!

Sincerely,

Wesley Carpenter
Doctoral Student
Department of Curricular and Instructional Studies
The University of Akron
Title of Investigation: Engineering Creativity: Toward an Understanding of the Relationship between Perceptions and Performance in Engineering Design

Name of Principal Investigator: Wesley Carpenter

1. This research project is being conducted by Wesley Carpenter, a doctoral student in the Department of Curricular and Instructional Studies at The University of Akron.

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been answered. I voluntarily agree to participate in this study. I will receive a copy of this consent form for my information.

________________________________  ________________
Participant Signature              Date

If you have any questions about this research project, you can contact Wesley Carpenter at wac1@uakron.edu. This research project has been reviewed and approved by The University of Akron Institutional Review Board for the Protection of Human Subjects. Questions about your rights as a research participant can be directed to the Institutional Review Board at 1-330-972-7666.

Thank you for your participation!

Sincerely,

Wesley Carpenter
Doctoral Student
Department of Curricular and Instructional Studies
The University of Akron
Dear [Name],

You recently completed an engineering design test entitled “The Creative Engineering Design Assessment” as a part of my research study. I mentioned that I would be interested in personally interviewing a few selected candidates; I am interested in interviewing you immediately. The interview will take place in the science library on the University of Akron campus at a day and time most convenient for you. The interview will take between 30-45 minutes.

As a condition of your participation, I will be offering you a monetary incentive of $20 in the form of a Visa gift card.

Please consider this opportunity and reply ASAP.

Regards,

Wesley A. Carpenter
wac1@uakron.edu
APPENDIX H

INTERNAL REVIEW BOARD NOTICE OF APPROVAL

February 13, 2015

Wesley Carpenter

From: Sharon McWhorter, IRB Administrator

Re: IRB Number 20150210 "Engineering Creativity: Toward an Understanding of the Relationship between Principles and Performance in Engineering Design"

Thank you for submitting your Exemption Request for the referenced study. Your request was approved on February 13, 2015. The protocol represents minimal risk to subjects and matches the following federal category for exemption:

☐ Exemption 1 – Research conducted in established or commonly accepted educational settings, involving normal educational practices.

☒ Exemption 2 – Research involving the use of educational tests, survey procedures, interview procedures, or observation of public behavior.

☐ Exemption 3 – Research involving the use of educational tests, survey procedures, interview procedures, or observation of public behavior not exempt under category 2, but subjects are elected or appointed public officials or candidates for public office.

☐ Exemption 4 – Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens.

☐ Exemption 5 – Research and demonstration projects conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine public programs or benefits.

☐ Exemption 6 – Taste and food quality evaluation and consumer acceptance studies.

Annual continuation applications are not required for exempt projects. If you make changes to the study's design or procedures that increase the risk to subjects or include activities that do not fall within the approved exemption category, please contact me to discuss whether or not a new application must be submitted. Any such changes or modifications must be reviewed and approved by the IRB prior to implementation.

Please retain this letter for your files. This office will hold your exemption application for a period of three years from the approval date. If you wish to continue this protocol beyond this period, you will need to submit another Exemption Request. If the research is being conducted for a master’s thesis or doctoral dissertation, the student must file a copy of this letter with the thesis or dissertation.

Co: N. Mahdi - Advisor
Co: Valerie Collins - IRB Chair

☒ Approved consent form/s enclosed
APPENDIX I

DEMOGRAPHICS QUESTIONNAIRE

E-mail________________________________

What is your academic rank? Please check the appropriate one
   ____ Junior
   ____ Senior
   ____ Graduate

What is your age? Please check the appropriate one
   ____ Under 18
   ____ 18-24
   ____ 25-34
   ____ 35-44
   ____ 45 and over

Ethnicity origin (or race): Please place a check beside your ethnicity.
   ____ White
   ____ Hispanic or Latino
   ____ Black or African American
   ____ Native American or American Indian
   ____ Asian / Pacific Islander
   ____ Other

What is your gender? Please check the appropriate one
   ____ Male
   ____ Female