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Engineering Creativity: Differences in Creative Problem Solving Stages Across Domains

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There is a growing call for enhancing creativity in engineering education. However, research indicates that most higher education institutions still lack the needed criteria for providing students with real-world experience that will hone their creative problem solving skills. Creating such environments requires a deeper understanding of different facets of engineering creativity. One key question is how engineering students across related disciplines demonstrate different strengths across the stages of the creative problem solving process. To study this issue, a sample of 505 engineering students was recruited from one northeastern university. Using the analysis of covariance statistical technique, this study compared engineering students on creative problem solving skills (specifically, problem recognition, idea generation, idea evaluation, and solution validation) and overall creativity. Multiple linear regressions were conducted to investigate the relationship between individual difference measures (such as gender, personality, and creative self-efficacy) and problem solving stages, as well as the possible association between these problem solving processes and specific desired educational outcomes (specifically, self-reported GPA, learning goals, performance goals, perceived ability, and academic interest in engineering). Additionally, two path analysis models were conducted to further investigate the association between the creative problem solving stages and overall creativity, and to explore how the three divergent thinking measures predicted the overall creativity. The findings of this research revealed that engineering students' scores on the problem recognition stage and overall creativity

varied based on engineering major and year in the engineering program. However, scores on the other creative problem solving stages (idea generation, idea evaluation, and solution validation) did not vary by major nor by year. Overall creativity was significantly associated with learning goals, perceived ability, and interest, but not with engineering students' performance goals. Path analysis models revealed that the quality of problem recognition and solution validation positively predicted creativity, whereas that the quality of idea generation and idea evaluation negatively predicted creativity. Divergent thinking measures positively predicted creativity. The core results emphasize the importance of problem recognition, domain knowledge, and experience in the creative process. These findings, along with past research, can be used to help advise engineering education to best nurture student creativity.

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DEDICATIONS

This dissertation is dedicated to my mother, Mariam Nazzal. Your endless love and constant prayers were foundational throughout my personal as well as my academic and professional life! I am forever grateful and honored to have you as my precious mom and lovely friend!

It is also dedicated in loving memory to my father, Jouries Nazzal, who has always been my steadfast pillar of support. Remembering his continuous doubtless confidence in my abilities helped me through this challenging process and made me a better scholar.

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CHAPTER 1: INTRODUCTION TO THE STUDY

Background of the Problem

For more than five decades, the United States has led the Science, Technology, Engineering, and Mathematics (STEM) disciplines; however, there is a new growing need for an educated and skilled STEM workforce to ensure America's continued competitiveness in a challenging global economy (Burke & Mattis, 2007; National Academy of Sciences, 2005). According to the National Conference of State Legislators (2010), there is a need to focus on the policies related to STEM education to improve the quality of education and to prepare students for jobs in the 21st Century workforce. Educational reform is especially essential in the engineering arena, because it is the field in which society's needs are met and its innovations are derived (National Academy of Engineering, 2008). The engineering profession primarily focuses on designing solutions to identified problems, and creativity is a vital tool for engineers who are responsible for developing these creative solutions (Charyton & Merrill, 2009; D. H. Cropley & Cropley, 2005).

Creativity has recently received much attention as an essential characteristic in the engineering problem solving process (Charyton & Merrill, 2009; D. H. Cropley, 2015); yet, it is still absent in contemporary engineering education (Kazerounian & Foley, 2007). The National Academy of Engineering (2013) highlighted engineering as an "inherently creative" profession (p. 1). Nonetheless, the term "creativity" or "creative" is absent in the US Accreditation Board for Engineering and Technology (ABET) definition of the engineering profession[1], and the only use of the term appears when they talk about "carry[ing] knowledge further toward creative

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[1] The US Accreditation Board for Engineering and Technology (ABET) defines engineering as "the profession in which a knowledge of the mathematical and natural science gained by study, experience, and practice is applied with judgment to develop ways to utilize economically, the materials and forces of nature for the benefit of mankind."

application" as one of the ABET accreditation criteria for academic programs curricula (Engineering Accreditation Commission, 2011, p. 4).

The need for developing learning environments that foster engineering creativity is evident in postsecondary education (Felder, 1987; Liu & Schonwetter, 2004). Engineers deal with real world problems, which are rarely neatly presented (Mumford, Baughman, & Sager, 2003), and thus engineering students should be trained to creatively solve open-ended ill-defined problems. Therefore, incorporating creativity into engineering curricula and learning environments in which students can grasp content knowledge while working on real-world problems (Heylen, Smet, Buelens, & Vander Sloten, 2007) is a necessity. However, creating environments better tailored to specific engineering domains requires a deep understanding of how different facets of engineering creativity are used within these disciplines. One key issue is the need to study the creative process to understand how students across different engineering domains may demonstrate different strengths across the stages of the problem solving process.

This study contributes to the current body of research by examining the nature of creative process across multiple engineering disciplines. Specifically, based on a four-stage model of creative problem solving, this research compares students from several engineering domains at one institution on the following skills: problem recognition, idea generation, idea evaluation, and solution validation. Additionally, this study investigates the relationship between individual differences and stages of the creative problem solving process. It also examines the possible association between these creative problem solving stages and specific desired educational outcomes.

Statement of the Problem

Despite the growing call for enhancing creativity in engineering education, creativity is still absent in most higher education institutions (Kazerounian & Foley, 2007), and new graduates are emerging from various universities lacking skills in creativity and problem solving (D. H. Cropley, 2015). Prior research on engineering creativity has mostly focused on the need to foster creativity. Curriculum reforms were suggested to foster creativity in engineering education (e.g., Chen, Jiang, & Hsu, 2005), and some courses were developed (e.g., "*Problem Solving and Engineering Design*") to introduce engineering students into real engineering practice (Heylen et al., 2007). Nevertheless, review of practice throughout higher education in the United States indicated the lack of deliberate training in creativity (D. H. Cropley, 2015). Addressing this problem requires a deeper understanding of different facets of engineering creativity. One fundamental issue is the need to understand how students in different engineering disciplines demonstrate different strengths and weaknesses across the creative problem solving process. The proposed study aims at exploring this issue.

Purpose of the Study

The purpose of this study is to investigate the creative problem solving process within engineering education. In particular, this study compares students across multiple engineering domains on different creative problem solving skills (specifically, problem recognition, idea generation, idea evaluation, and solution validation) and examines the ways these stages differentially predict both each other and overall creativity. In addition, this research explores the way that the quality and creativity of the creative process relate to some desired academic outcomes while also taking into consideration the effect of individual difference variables (such

as personality traits and creative self-efficacy). These findings can be used to better inform engineering curricula and pedagogical techniques that can enhance creativity development.

Research Questions

The purpose of this study is to address the following questions:

1. Do students across different engineering domains and at different stages of their education demonstrate different patterns of strengths in creative problem solving skills (specifically, problem recognition, idea generation, idea evaluation, and solution validation)?
2. Do individual difference variables (such as gender, personality, and creative self-efficacy in engineering) differentially predict engineering creativity and problem solving quality?
3. Are different parts of the creative problem solving process associated with specific desired academic outcomes (such as self-reported GPA, engagement with engineering (measured as with both learning and performance goals), perceived ability in engineering, and academic engineering interest)?

Hypotheses

There is a relative lack of research on creative problem solving stages in engineering. Therefore, hypotheses proposed for the research questions are more exploratory and rooted in the general creativity literature. The hypotheses are:

Hypothesis 1: Differences will be observed among students in different engineering majors with regard to their problem solving skills.

Hypothesis 2: Differences will also be observed among engineering students in different levels (year in the engineering program) with regard to their problem solving skills.

Hypothesis 3: Individual differences variables will predict some percentage of the quality and creativity of engineering students' creative problem solving.

Hypothesis 4: Creative problem solving skills will be associated with academic outcomes, such as engagement, perceived ability, and academic interest in engineering.

Theoretical Framework

Over the course of nearly the past century, scholars and researchers have been studying the creative process and have found that creativity tends to occur in a sequence of stages. Creativity theorists have proposed different models of the creative process cognitive skills (e.g., Mumford, Mobley, Uhlman, Reiter-Palmon, & Doares, 1991; Sawyer, 2012; Sternberg, 2006; Wallas, 1926). Drawing from the key stages of creative problem solving, a four-stage model of creative problem solving (problem recognition, idea generation, idea evaluation, and solution validation) was selected to provide the theoretical framework of the proposed research.

Grounded in more than 60 years of research, these four stages were articulated by Cropley (2015), drawing heavily from Guilford (1959), to be the foundation for understanding the main stages needed for creative problem solving in engineering. Likewise, these four stages strikingly correspond to the four criteria emphasized in the *Next Generation Science Standards* (NGSS) to define engineering design: identifying the problem in terms of criteria for success and constraints, generating potential solutions, evaluating the solutions in light of the criteria and constraints, and choosing the best solution to implement (NGSS, 2013). Further, this stage-based approach ties to the phases of design thinking concept proposed by several scholars as a way for investigating ill-defined problems, focusing on the *process* of the problem solving rather than the *product* per se (e.g., Brown, 2008). These four stages of creative problem solving are explained in detail in Chapter 2.

Summary of Methods

The sample for this study consisted of 505 engineering students attending a northeastern public university. The students were recruited from different engineering disciplines and at different levels in their programs. A convenience sampling method was used to recruit undergraduate engineering students from all different engineering domains. Overall, sample members were of age 18 or older enrolled in an engineering program.

Participants completed several sets of measures: (a) demographic information form (gender, age, specific engineering major, and year in the engineering major); (b) a general engineering-related, ill-defined, problem-solving task with a series of questions; (c) individual differences measures (personality and creative self-efficacy in engineering); (d) specific academic outcomes (learning goals, performance goals, perceived ability in engineering, and academic interest in engineering); and (e) a domain-specific knowledge measure. More details about these measures are presented in Chapter 3; they are included in their entirety in Appendices A through G.

Participants' responses were scored using the Consensual Assessment Technique (CAT, Amabile, 1996). According to this method, experts from the relevant field are the best and the most appropriate judges of creativity in the domain (J. C. Kaufman, Baer, & Cole, 2009). However, given the difficulty in obtaining high-level experts to serve as raters for a large sample, and as proposed by J. C. Kaufman and Baer (2012), quasi-experts were used for this study. Studies have shown that advanced students in a field (J. C. Kaufman, Baer, Cropley, Reiter-Palmon, & Sinnett, 2013; J. C. Kaufman, Gentile, & Baer, 2005), and both experts and quasi-experts in the domains of teaching and creativity research (Baer, Kaufman, & Riggs, 2009; J. C. Kaufman et al., 2013) tend to agree at a reasonable level with actual experts.

Using this methodology, I recruited several quasi-experts from within the fields of education, creativity research, and the domain in question (engineering). Consistent with past Consensual Assessment Technique work (Amabile, 1996), working alone and primarily relying on their personal definitions of the concepts of creativity and quality, the raters assigned scores to each of the responses. Inter-rater reliability were evaluated with Cronbach's (1951) coefficient alpha. Procedures of scoring the four stages slightly differed. Further details of the scoring protocol are explained in the methods section in Chapter 3. Overall, each student was assigned several scores: problem recognition, idea generation, idea evaluation, solution validation, and overall creativity score; in addition, there were three divergent thinking scores: fluency, flexibility, and originality.

Descriptive statistics and a correlation matrix were computed. Two-way between-groups ANOVAs were used to answer the first research question. A series of multiple linear regression was conducted to answer research questions 2 and 3. In addition, two path analysis models were run to thoroughly capture the relationship between the quality of creative problem solving stages and overall creativity, as well as the association between the divergent thinking measures and overall creativity. Details of data analyses are presented in Chapter 3.

Significance of the Study

The differences in strengths and weaknesses that I anticipate to find in my study are noteworthy for educational policy development because of at least two reasons:

- Students who are skilled in the application of a specific stage of the creative process will likely be attracted to domains in which these processes are emphasized (Schneider, 1987).

- Selection into the domain will tend to focus on those processing skills that are critical to creative performance within the relevant domain (Csikszentmihalyi, 1999).

CHAPTER 2: REVIEW OF LITERATURE

Engineering

Engineering is an applied science whereby engineers solve problems and derive innovations (National Academy of Engineering, 2008). Engineers integrate different types of skills and knowledge in an effort to discover ways to improve the public's lives by "creating bold new solutions that connect science to life in unexpected, forward-thinking ways" (National Academy of Engineering, 2008, p. 5). Buhl (1960) stated that engineers must be creative at every stage of problem solving in order to create new products and processes to fulfill the needs. Engineers that are "equipped with the blend of technical knowledge and creativity" are needed to design solutions to satisfy humankind's needs and desires (D. H. Cropley, 2015, p. 49). A recent report of the National Academy of Engineering highlighted the importance of improving public understanding of this profession in order to attract young students to engineering careers by "cast[ing] engineering as inherently creative" field and engineers as "creative problem-solvers" (National Academy of Engineering, 2013, p. 1).

Engineering Design is considered the central activity of the field of engineering (Simon, 1996). Engineering educators Katehi, Pearson, and Feder (2009) have defined engineering design as "the engineering approach to identifying and solving problems" (p. 4). They further argued that engineering design as a problem-solving process is a "potentially useful pedagogical strategy" that provides students with opportunities to apply mathematical and scientific concepts to create different solutions to identified problems (p. 4). The NGSS (2013) propose that engineering design should include identifying the problem in terms of criteria for success and constraints, generating potential solutions, evaluating the solutions in light of the criteria and constraints, and choosing the best solution to the problem.

Katehi et al. (2009) emphasized that teaching engineering at the K-12 level has a conceptual connection to post-secondary education and to the practice of engineering in the real world. This approach stresses three principles: (a) emphasizing the design process as an engineering approach of problem-solving; (b) incorporating important and developmentally appropriate knowledge and skills; and (c) promoting engineering "habits of mind" such as systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations (p. 5). One could argue, thus, that engineering education at the college level should mirror these principles.

However, engineering researchers Kazerounian and Foley (2007) argued that these conceptions are not reflected in the way that universities currently prepare future engineers. They posited that "creativity is not valued in the contemporary engineering education" (p. 762). They have proposed the *Ten Maxims of Creativity* necessary for a creative environment, and the results of their research showed that current engineering education lacks almost all of these criteria. They found that engineering students lack a creative work process; specifically, the concept of *search for multiple answers* was perceived as conceptually foreign. However, their findings also indicated that engineering students have the most room for creative improvement (in comparison to their counterparts in the sciences and humanities). Engineering curriculum and pedagogical practices need to be improved, which can thus lead to learning environments that require and reward creativity (Kazerounian & Foley, 2007).

Incorporating creativity in postsecondary engineering education is a necessity. The ultimate educational goal is to create learning environments in which students can be grasping the content while working on real-world problems that will better prepare them to be professional engineers. As scholars and educators, we need to first understand how different

facets of engineering are related to creativity. One key issue is the need to understand how engineering students across different disciplines demonstrate different strengths in the creative problem solving process. To explore these questions, I will provide a brief review of the related literature on creativity and creative problem solving.

Creativity

Creativity has received continued attention within the fields of psychology and education since Guilford's (1950) presidential address at the American Psychological Association. Existing definitions of creativity highlight two key components describing this construct—originality (novelty) and task appropriateness (usefulness) (e.g., Amabile, 1983; Reis & Renzulli, 1991; Simonton, 2012; Sternberg, 1999; Sternberg, Kaufman, & Pretz, 2002). Other scholars have added a context-relevance factor and introduced the definition in a form of mathematical equation (i.e., $C = [O \times A]_{Context}$); that is, creativity produces an original product that is task-appropriate in a particular context (Beghetto & Kaufman, 2014; Simonton, 2012). Based on a synthesis of reoccurring themes across the creativity literature, Plucker, Beghetto, and Dow (2004) offered the following definition of creativity: "Creativity is the interaction among *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). This definition underlines the four Ps introduced by theorists to classify creativity: Person, Product, Process, and Press. The four-Ps framework, first introduced by Rhodes (1961), helps differentiate among talking about the creative person (who is involved in the creative act), the creative product (output produced by the creative act), the creative press (where and when the creative act is taking place), and the creative process (the cognitive strategies used during the creative act).

Different theories of creativity can be classified according to which "P" is primarily

emphasized (J. C. Kaufman, 2009; Kozbelt, Beghetto, & Runco, 2010). Although some scholars have argued that the most important aspect of engineering creativity is the product that performs tasks or solves problems (D. H. Cropley & Cropley, 2005), the creative process that is used by the creative person is also a vital component to understand engineering creativity (J. C. Kaufman, 2009). Further, the creative process is tied to the domain in which it is happening. According to Csikszentmihalyi (1999), the domain is a necessary component of creativity because a specific domain dictates how the information is recorded and determines how well the information is integrated; further, creativity is related to how the domain is central to, accessible by, and autonomous from the rest of the culture.

The creativity literature, as with most other research arenas, is filled with different debates; one of these is the question of whether creativity is more domain-general or domain-specific (see for example, Plucker, 2004; Plucker & Beghetto, 2004; Sternberg, 2005). Although this is an ongoing discussion, a large body of research disputes both extreme approaches and suggests a "hybrid position" of this debate (e.g., Plucker & Beghetto, 2004; Sternberg, 2005). In other words, the nature of creativity is partly general, partly domain-specific, and partly task-specific (Lubart & Guignard, 2004). Creativity scholars have proposed theoretical models to interweave the domain-specific and domain-general approaches of creativity.

One such model is the Amusement Park Theoretical model (APT; Baer & Kaufman, 2005; J. C. Kaufman & Baer, 2004, 2005), which argues that creativity has domain-specific aspects as well as domain-general features. According to this theory, 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 visual art,

writing, math, and science). They then extend the model to include domains (i.e., poetry) and microdomains (i.e., Haikus).

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 (D. H. Cropley, 2015) and qualify as initial requirements, the specific strengths and weaknesses throughout the creative problem solving procedure should vary by domains (J. C. 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.

The question arises as to whether differences in effective execution of creative processing

skills will be observed within one thematic area such as engineering, but across multiple domains (such as civil, electrical, mechanical, biochemical, and biomedical). To investigate that question I will first review the stages that are essential in the creative problem solving process.

Creative Problem Solving Models

As stated by Sawyer (2012), philosophers have developed two competing theories of the creative process: Idealist Theory (stating that the creative process is all about the creative idea) and Action Theory (arguing that the execution of the creative work is essential to the creative process). Sawyer argued that the Idealist Theory is false and that creativity takes place over time and most of it occurs while doing the work. Over the course of nearly the past century, scholars and researchers have been studying the creative process and have found that creativity tends to occur in a sequence of stages. Creativity theorists have proposed different models of the creative process cognitive skills starting from a simple two-stage model (a *divergent thinking* stage in which ideas are generated followed by a *convergent thinking* stage in which the best idea is chosen, comparable to Finke, Ward, and Smith's (1992) Geneplore Model); and then expanding upon it to three stages or more. Some examples of these models include Wallas's (1926) four-stage model; Sternberg's (2006) seven-stage model; and Mumford et al.'s (1991) eight-stage model. Sawyer (2012) described an integrated eight-stage framework capturing the key stages of all of the various proposed models (find and formulate the problem, acquire knowledge relevant to the problem, gather a broad range of potentially related information, take time off for incubation, generate a large variety of ideas, combine ideas in unexpected ways, select the best ideas by applying relevant criteria, and externalize the idea using materials and representations). Table 2.1 summaries these proposed models and the key stages of the creative process.

Table 2.1. *Different Models of Creative Process*

Wallas (1926)	**Osborn-Parnes (1953; 1967)**	**Guilford (1959)**	**Mumford et al. (1991)**	**Higgins (1994)**	**Sternberg (2006)**	**Sawyer (2012)**
	Objective finding	Problem recognition	Problem definition	Problem identification, making assumptions about the future	Redefine problems	Find the problem
Preparation	Fact finding		Information gathering		Know the domain	Acquire the knowledge
	Problem finding		Information organization			Gather related information
Incubation			Conceptual combination		Take time off	Incubation
	Idea finding	Idea generation	Idea generation	Generation of alternatives	Generate ideas	Generate ideas
					Cross-fertilize ideas	Combine ideas
	Solution finding	Idea evaluation	Idea evaluation	Choice of alternatives	Judging ideas	Select the best ideas
Illumination			Implementation planning			
Verification	Acceptance finding	Solution validation	Solution appraisal		Sell the idea, persevere	Externalize ideas

Drawing from these key stages, I have selected a four-stage model of creative problem solving (problem recognition, idea generation, idea evaluation, and solution validation) to provide the theoretical framework of the proposed research. These four stages were articulated by Cropley (2015), drawing heavily from Guilford (1959), to be the foundation for understanding the main stages needed for creative problem solving in engineering. Likewise, as presented in Table 2.2, these four stages correspond nicely to the four criteria emphasized in the NGSS to define engineering design: identifying the problem in terms of criteria for success and constraints, generating potential solutions, evaluating the solutions in light of the criteria and constraints, and choosing the best solution to implement (NGSS, 2013). Further, they tie to the phases of design thinking concept (e.g., Brown, 2008) that have been adopted by several businesses and

institutions as an approach for investigating ill-defined problems, focusing on the *process* of the problem solving rather than the *product* per se.

Table 2.2. *Four-Stage Model of Creative Problem Solving and How it Corresponds to Stages of Engineering Design*

Four-Stage Model	**Description**	**Engineering Design (NGSS, 2013)**	**Design Thinking (Brown, 2008)**
(D. H. Cropley, 2015)			
Problem recognition	Recognition that a problem exists	Identifying the problem	Problem finding and framing
Idea generation	Production of a variety of relevant ideas	Generating potential solutions	Ideation/ brainstorming
Idea evaluation	Evaluation of the various possibilities produced	Evaluating the solutions	Prototyping
Solution Validation	Drawing of appropriate conclusions that lead to the solution of the problem	Choosing the best solution	Testing & Reiterating

The following sections of this literature review provide a brief explanation of each of the four stages.

Four-Stage Problem Solving Model

Engineering profession involves dealing with real world problems. However, real world problems are rarely neatly presented (Mumford et al., 2003), and thus engineering students should be trained to creatively solve open-ended ill-defined problems. Thus, this model of problem solving process assumes such a problem on hand.

Problem Recognition

Researchers have discovered that creativity often results when individuals work on unspecified problems (Csikszentmihalyi, 1965). These results made many creativity theorists believe that *problem finding* is as important as *problem solving* for the creative process (Reiter-Palmon, Mumford, O'Connor Boes, & Runco, 1997). Thus the first stage in the creative process is the identification of a problem among several ones. This phase is convergent in nature and

requires precisely recognizing and defining the one problem that needs to be solved (D. H. Cropley, 2015). Problem recognition entails finding the good problems (Getzels & Csikszentmihalyi, 1976; Tardif & Sternberg, 1988). A "good" problem is one that will be helpful to the situation at hand, as well as will yield to generalizable solutions beyond the present need (D. H. Cropley, 2015).

Although different scholars have suggested slightly different theoretical models to explain the creative process (see Table 1), almost all of them included problem recognition (they also used various terms such as problem definition, problem identification, and problem construction) as the first step. These theorists highlighted the significance of this first stage of the creative process; however, empirical studies did not begin until Getzels and Csikszentmihalyi's (1976) study that indicated the impact of problem identification and construction on long-term success of art students.

Since the 1990s, much more work has been done on problem recognition (e.g., Runco, 1994) and additional theoretical frameworks have been developed (e.g., Mumford, Reiter-Palmon, & Redmond, 1994) to better explain factors influencing and shaping this stage of the creative process. Reiter-Palmon et al. (1997) tested the hypotheses in Mumford et al.'s (1994) model and found that undergraduates with high problem construction ability produced solutions of higher quality and originality for leadership, social, and school problems (the results showed only marginally significant effects of originality for the social and school problems). As part of a series of studies on process-based measures of creative problem-solving skills, Mumford, Baughman, Threlfall, Supinski, and Costanza (1996) developed a test to assess problem construction based on the model proposed by Mumford et al. (1994). Their results suggest that "the use of high-quality procedures in problem construction can influence creative problem

solving on tasks drawn from different domains" (Mumford et al., 1996, p. 75). That suggests that viable framing of an ill-defined problem would positively affect the next stages of the creative process, starting with generating potential ideas.

Idea Generation

After identifying a good problem to solve, the second stage is to generate multiple solutions to the ill-defined problem. This stage involves divergent thinking given that the problem-solver is dealing with an open-ended, ill-defined problem; consequently, the solution will not be clear at first. The task for this stage is to generate many different ideas that might be potential solutions to the problem that was identified in the first stage. Generating ideas is more than brainstorming; it is exploring ideas that are possible solutions of the problem at hand (Creative Education Foundation, 2014). It involves, as stated by Treffinger (1995), "fluent thinking" (producing many options), "flexible thinking" (creating a variety of possible options), "original thinking" (making novel options), and "elaborative thinking" (forming detailed options). According to Cropley (2015), this stage is where the creator moves from having one identified problem (convergence) to a variety of ideas (divergence).

Although this stage is primarily listing ideas, it nonetheless requires knowledge and expertise in the specific domain (Vincent, Decker, & Mumford, 2002). The goal at this stage is not only to generate ideas, but also to come up with as many good potential solutions to the problem as possible. Information about the problem structure (from the first stage) along with concepts of the given domain provide the basis for generating alternative ideas (Runco & Chand, 1994)

Prior research has revealed that creativity is enriched by a close linkage between divergent and convergent thinking; real-world creativity requires both idea generation and idea evaluation

abilities (Runco, 2003). Silvia (2008) found a correlation between idea generation and evaluation abilities; people who generated more ideas were better at evaluating them. Hence, performing well at this stage enables strong performance on the next.

Idea Evaluation

After generating many potential solutions to the problem, the problem-solver needs to find the best solution. The task of the third stage is to evaluate these solutions in terms of criteria for success and test them against the constraints to choose the optimal one. Cropley (2015) asserted that this phase is when the problem-solver needs to eliminate nearly all of ideas generated in the second phase to arrive at only one solution; that is, this stage is convergent in nature. He argued that whereas the potential for success drives the stage of “idea generation,” the constraints are typically what play a vital role in the “idea evaluation” stage—the constraints give the criteria against which the alternatives would be judged.

In this phase, the creator needs to draw on his or her knowledge about the domain in order to evaluate the ideas (Runco & Chand, 1994, 1995), in addition to other evaluative criteria such as novelty and appropriateness (R. K. Sawyer, 2012). Accordingly, the novel solution that both addresses the need and meets the constraints will be chosen.

Scholars have discussed the importance of the idea evaluation phase under different terms such as verification (Wallas, 1926), convergent thinking (Isaksen & Treffinger, 1985), and evaluative skill (Runco & Chand, 1995; Runco & Smith, 1992). Other scholars proposed models of the idea evaluation process (e.g., Mumford, Lonergan, & Scott, 2002; Wilson, Guilford, Christensen, & Lewis, 1954). Blair and Mumford (2007) identified different attributes that people use when evaluating ideas. They found that people are likely to choose ideas that fit social norms, produced the desired outcome quickly, were complex to implement yet easy to

understand, and benefited many people. A related study revealed that people consider two issues when they evaluate ideas: the resources needed to implement the idea, and the consequences of implementing the idea (Dailey & Mumford, 2006). This finding leads us to the last stage of the creative process.

Solution Validation

Given that the primary purpose is to successfully solve the problem, the last stage is validating the best solution and then implementing it. This stage is convergent in nature and requires connecting the chosen solution back to the initial problem; it simply brings all the stages together to confirm that all stages were executed correctly and were integrated into an actual solution of the problem at hand (D. H. Cropley, 2015). Although creativity research tends to focus on earlier stages of the creative process, a great deal of creativity occurs at this stage (R. K. Sawyer, 2012). A creative and applicable idea is not validated as a useful solution if it is not implemented.

The creator, especially in practical domains (such as technological invention, engineering, and entrepreneurship), needs to be skilled at executing ideas, identifying the necessary resources to make them successful, forming plans for implementation, and anticipating to adjust the plans in the future (Mumford, 2003; Policastro & Gardner, 1999). Sawyer (2012) claimed that this phase requires more than a straightforward execution of the idea; it entails creatively making the idea a reality as well as generating potential follow-up ideas. He further argued that creative people do not wait until their idea is fully formed before they start externalizing it; rather, they start putting together at the early stages. He further argued that for successful creators, this stage is essential to the problem-finding phase. This view ties all of the four stages together.

Assessing students within the engineering domain on these stages of problem solving

would help to investigate their different strengths within the creative process. Potential findings can provide insights that will inform engineering education and improve current learning environments to better prepare professional engineers. My research aimed to examine how individual difference variables impact these creative problem solving processes. As well, this study aimed to investigate the possible association between these stages and some desired academic outcomes.

Individual Differences Variables

Scholars have long been interested in individual and environmental characteristics that may influence creative thought and achievement (Csikszentmihalyi, 1999; Mumford et al., 2010). Research has showed that many variables (including personality and creative self-efficacy) might contribute to cross-field differences in creativity and creative performance (e.g., Choi, 2004; Feist, 1999). However, limited research has been produced which investigates differences in creativity and creative performance across engineering domains (D. H. Cropley, 2015). Although creative problem solving has not been studied thoroughly in engineering, one can argue that it may be affected by the same variables that are important in the rest of the creativity literature. I will examine the following variables as potential predictors of engineering undergraduates' creative problem solving skills: engineering major, year in engineering program, gender, personality, and creative self-efficacy.

Engineering Major

Prior research has indicated that there are cross-field differences in the creative processing skills (Mumford et al., 2010). These scholars argue that the creative problems presented in different fields would differ in the type of skills needed in the execution of the relevant creative thinking processes. In this study, I further argue (based on the Amusement Park

Theory explained above) that potential differences will be observed across multiple domains within one thematic area. That is, for example, different engineering domains might differ in the type of problems they solve, or even in the way they would solve the same problem (Bruch & Krieshok, 1981; Veurink & Sorby, 2013). Differences in the type of problem found across engineering domains might characterize the creative work conducted within these domains. In my study I aim at investigating such potential differences in the stages of creative problem solving across multiple engineering domains (specifically as biomedical, chemical, civil, computer science, electrical, environmental, materials, and mechanical).

Year in the Engineering Program

One could expect that practice in a domain might lead to improvement in student's application of domain-relevant creative skills as a result of knowledge and experience (Weisberg, 2006). However, as Mumford et al. (2010) argued, the patterns of growth and change observed in creative thinking processes may be quite complex with at least three different patterns of change potentially being observed with experience: (a) gains in field-relevant processing skills, (b) no change, and (c) decrements in field irrelevant processing skills. Therefore, it is possible that either growth or decline of creative processing skills might occur as people advance in a given field (Mumford et al., 2010).

It simply seems that more experience in a field would result in the acquisition of stronger declarative and procedural knowledge (Chi, Bassok, Lewis, Reimann, & Glaser, 1989), which should, in turn, result in gains in field-relevant processing skills. Presumably, such experiences would result in the growth of field-relevant skills in the application of creative problem-solving processes. Nevertheless, it is also plausible that little, or no, change in requisite processing skills would be observed as people enter a field. Upon people's entry into a field, there is an

acquisition of declarative knowledge. During this initial time, there is often a focus on basic concepts. It takes more time to acquire the procedural knowledge or strategies that lead to more effective application of creative thinking processes (Ericsson & Charness, 1994). Consequently, growth in field-relevant creative thinking processes might not occur. Finally, a third possibility might be observed. Declines in some creative processing skills may be observed as people enter a field for different reasons: (a) people will be more invested in pursuing work within the domains of interest, and consequently, the growth of these creative processing skills may be slowed; (b) a person might be provided with negative feedback regarding the application of inappropriate problem-solving strategies (Zuckerman, 1977), which may lead to declines in the application of any creative thinking processes; or (c) people with too much knowledge might become inflexible (Frensch & Sternberg, 1989; Schooler & Melcher, 1995), or have the tendency to rely on standard examples to generate new ideas (Ward, 1995; Ward, Dodds, Saunders, & Sifonis, 2000; Ward & Kolomyts, 2010).

In my study I will investigate which of these patterns might be affecting the engineering undergraduates, across multiple domains, at different levels of their college experiences.

Gender

Research shows that females are significantly less likely to declare a STEM major (e.g., Goyette & Mullen, 2006; Nicholls, Wolfe, Besterfield-Sacre, Shuman, & Larpkiattaworn, 2007), or to graduate with a STEM major compared to their male non-minority counterparts (Griffith, 2010; National Science Foundation, 2008, 2011; Seymour & Hewitt, 1997). Specifically, there is a disparity between the number of male and female engineering graduates. In 2005, women received 58 percent of the bachelor's degrees awarded in all fields, but only 43 percent in physical sciences, 22 percent of computer sciences degrees, and 20 percent in engineering (Hill,

Corbett, & Rose, 2010; National Science Foundation, 2008). However, this discrepancy is less evident in creativity literature.

Reviewing extensive literature that reports gender differences on creativity tests, Baer and Kaufman (2008) found that no simple result could be taken. That is, where some studies showed that men do better than women, others that women do better, and other studies found no difference. Nonetheless, they further argue, the general trend in these studies mirrors the larger cognitive findings in achievement tests (i.e., women score higher on verbal measures and men score higher on figural/mathematical measures). In a recent study on divergent thinking, Hong, Peng, O'Neil, and Wu (2013) found where is no differences in domain-general divergent thinking, differences appear on domain-specific divergent thinking—women scored higher on fluency, flexibility, and elaboration.

However, a large body of research on gender differences in creativity revealed inconsistency between gender differences on creativity tests and actual creative accomplishment (J. C. Kaufman, 2009). Despite the fact that creativity tests reveals minor and inconsistent gender differences, differences in real-world creative accomplishment are large and significant (Murray, 2003; Simonton, 1994). In a review of human accomplishment, Murray (2003), notes that out of 4,002 eminent people he categorized as "significant," only 88 (two percent) were female. Furthermore, he found that only four percent of all Nobel Prize winners from 1901-1950, and only three percent of all winners from 1951-2000 were women. A similar male-dominance trend found by Piirto (1991). It was found that girls' comparative lack of creative achievement does not appear until after high school and college, which indicates that the issue might be a conflict between personal vs. professional demands (Piirto, 1991).

The study of gender as a variable affecting creative problem solving in engineering is necessary due to: (a) the disparity between male and female graduates in engineering, and (b) the inconsistency between gender differences in creativity and actual creative accomplishment. In this study I examine gender difference in the creative problem solving stages across different engineering domains.

Personality

Personality is one of the most commonly studied attributes associated with creativity. The most widely used theory is the Five Factor theory of personality (Goldberg, 1992). This theory summarizes the different possible personality components under five factors (sometimes called the “Big Five”): neuroticism, extroversion, openness, conscientiousness, and agreeableness (J. C. Kaufman, 2009). Each of these factors measures a specific trait of the human nature. Neuroticism measures a person’s emotional stability, extroversion measures how sociable a person is, openness to experience expresses an individual’s intellectual and experiential curiosity, conscientiousness taps into one’s discipline and integrity, and agreeableness means being friendliness and good-natured (J. C. Kaufman, 2009; Kyllonen, Walters, & Kaufman, 2005; McCrae & Costa, 1997). Openness to experience is consistently the factor that is most associated with a wide variety of creativity measures; one common way that researchers study creativity is by giving openness-to-experience-type of questions (J. C. Kaufman, 2009). This connection has been shown across multiple domains. In his extensive meta-analysis, Feist (1998) found that creative scientists were more open to experience than less-creative scientists, and artists were more open to experience than non-artists.

As reviewed by Kaufman (2009), many of the other personality factors show strong domain effects. For example, scientists are more apt to be disagreeable and conscientious,

performers are more likely to be extroverted, and fine artists are more likely to be introverted and not conscientious. Very few studies have examined the relationship between creativity and personality within engineers, particularly across stages of the creative problem solving process. Personality has been included as a potential predictor variable for this reason.

Creative Self-Efficacy

Self-efficacy, as a broad construct introduced by Bandura (1997), is how someone judges his or her specific abilities to succeed in a given task. This judgment might influence effort, persistence, and, ultimately, the achievement of a given outcome. Bandura further recognized a likely relation between self-efficacy and creative performance; he states, "innovativeness requires an unshakeable sense of efficacy to persist in creative endeavors" (1997, p. 239). Research indicates that creative performance is influenced by someone's self-efficacy for his or her creative abilities (Tierney & Farmer, 2002). Creative self-efficacy has been defined as "the belief one has the ability to produce creative outcomes" (Tierney & Farmer, 2002, p. 1138).

Examining students' creative self-efficacy may be useful in supporting the growing creativity enhancement efforts of educators and creativity scholars (e.g., Feldhusen & Treffinger, 1985; Renzulli & Reis, 2014; Torrance, 1987). Specifically, as stated by Beghetto (2006), it will be useful to know how students' experiences are related to their creative self-efficacy, and how academic beliefs and behaviors are associated with varying levels of creative self-efficacy. In this study I intend to investigate the potential relationship between engineering students' creative self-efficacy and their creative problem solving skills.

Academic Outcomes

Research on higher education has primarily focused on student success and desired academic outcomes (Astin, 1993; Pascarella & Terenzini, 2005; Tinto, Russo, & Kadel, 1994).

In particular, a large body of engineering education research focuses on student persistence and tries to find ways to retain undergraduates in the engineering majors (Felder, Woods, Stice, & Rugarcia, 2000; Knight, Carlson, & Sullivan, 2007). There is a consensus in the literature that college students are more likely to be successful in their college studies if they have strong perceived ability, are engaged in their courses, and demonstrate interest in their programs (e.g., Greven, Harlaar, Kovas, Chamorro-Premuzic, & Plomin, 2009; Kuh, 2003a; Renninger, Hidi, & Krapp, 2014). The engineering domain is a not an exception, and thus, these variable are expected to be also useful in engineering education.

In my study I seek to examine if specific creative problem solving skills positively relate to desired academic outcomes in engineering students, such as student Grade Point Average (GPA), academic engagement, perceived ability, and interest in engineering.

Grade Point Average (GPA)

Student Grade Point Average (GPA) has been historically considered one of the most important predictors and outcomes of student success (R. Sawyer, 2013; Zwick, 2013). The relationship between GPA and creativity is mild at best (Grigorenko et al., 2009), but specific strengths in creative problem solving have not been studied in relation to GPA. Given GPA's prevalence in the academic realm, its inclusion as an outcome variable seemed appropriate.

Academic Engagement

Engagement inside the classroom is of particular importance to student development (Astin, 1993; Tinto et al., 1994). Research on college student learning indicates that students who are actively engaged in their academic activities gain more from their college experience compared to students who are not actively engaged (Pascarella & Terenzini, 2005). Prior research on engineering persistence indicated that there is an association between academic

engagement and persistence (Ohland et al., 2008). Thus, there is a pressing need for efforts to improve academic engagement of college students in general, and engineering students in particular. These efforts are widely perceived to be one key to improving the educational experience of undergraduate students (e.g., Kuh, 2003a, 2003b).

Research on academic engagement further investigated the culture of engagement in different disciplines. Brint, Cantwell, and Hanneman (2008) found that there are two different cultures of academic engagement: the "humanities/social sciences culture of engagement", and the "natural sciences/engineering culture of engagement" (p. 390). They point out that the culture of engagement in the natural sciences and engineering focuses on improvement of quantitative skills and it can generate hard work, collaborative study, and technically competent performances.

Thus, understanding the nature of engagement in engineering higher education is needed to improve students' persistence in engineering domains. One key investigation is to study the potential relationship between students' creative skills and their academic engagement in engineering disciplines. Reasons for student academic engagement could be related to learning goals (where the purpose of their engagement is gaining knowledge) or performance goals (where students engage in an activity to prove their competence; Elliot & McGregor, 2001). Whereas learning goals are associated with intrinsic motivation, performance goals are related to extrinsic motivation (J. C. Kaufman, 2009). Therefore, understanding the role that learning goals as well as performance goals may play in the creative process is of significant importance.

Perceived Ability

Researches have found that several constructs other than IQ tests are also important predictors of academic achievement, one of which is self-perceived ability (Greven et al., 2009).

Greven et al. (2009) state that self-perceived abilities (or how good people think they are) proved useful in predicting academic achievement after controlling for IQ measures. In the past few decades, scholars paid a special attention to this construct as a vital predictor of students' performance. Some studies have indicated that students' self-perceived abilities predict their school performance independent of their IQ scores (Schicke & Fagan, 1994; Spinath, Spinath, Harlaar, & Plomin, 2006). In addition, in a longitudinal study, Valentine, DuBois, and Cooper (2004) found that students' self-perceived abilities had a small but consistent impact on academic achievement after controlling for previous achievement.

College students' perceived ability is an important factor that affects academic achievement. Therefore, there is a need to investigate potential associations between students' perceived abilities and other academic constructs, such as creativity.

Academic Interest

Research on academic interest started over a hundred years ago. Dewey (1913) was the first to highlight the vital role of academic interest in learning. He believed that it is interest, rather than effort, that leads to deeper learning. According to him, interest as a construct (a) should be present in the classroom, and (b) could be fostered by providing students with opportunities that promote challenge and autonomy. In addition, later studies explicitly addressed the relationship between interest and learning and indicated that a positive relationship between interest and learning exists (Kintsch, 1980; Renninger et al., 2014). Scholars have found that interest in activities may increase the likelihood that individuals consider goals related to these activities and invest time and effort to achieve them (Bandura, 1986; Renninger et al., 2014). Other researchers have related high levels of interest to engagement and persistence at a given task (Csikszentmihalyi & Nakamura, 1989; Deci, 1992).

Investigating academic interest is central to understanding the underlying reasons for why students perform well the way they do, and thus, to promote opportunities that foster interest in the classroom (Schraw, Flowerday, & Lehman, 2001). My study will examine the potential relationship between engineering students' creative skills and their developed interest in the engineering courses.

CHAPTER 3: RESEARCH METHODS

Research Design

In this study, quantitative procedures were used to investigate the hypothesized differences in creative problem solving processes among students across several engineering domains at one northeastern university.

Sampling

The sample consisted of 505 engineering students attending one northeastern university. The students were recruited across different engineering disciplines and at different levels in their programs. The office of the Associate Dean of Undergraduate Education and Diversity provided names, majors, and email addresses of the students in the School of Engineering at that specific university. A multi-stage process was used to recruit students in the different engineering programs. First, engineering faculty announced the study in their classes. Second, the Office of the Associate Dean of Undergraduate Education and Diversity sent emails directly to all engineering undergraduates requesting participation in the study. A convenience sampling method was used to recruit undergraduate engineering students from all different engineering domains. Overall, sample members are of age 18 or older, males and females, at different levels of engineering programs. See Figures J.1 through J.3 for gender, major, and year statistics for the sample.

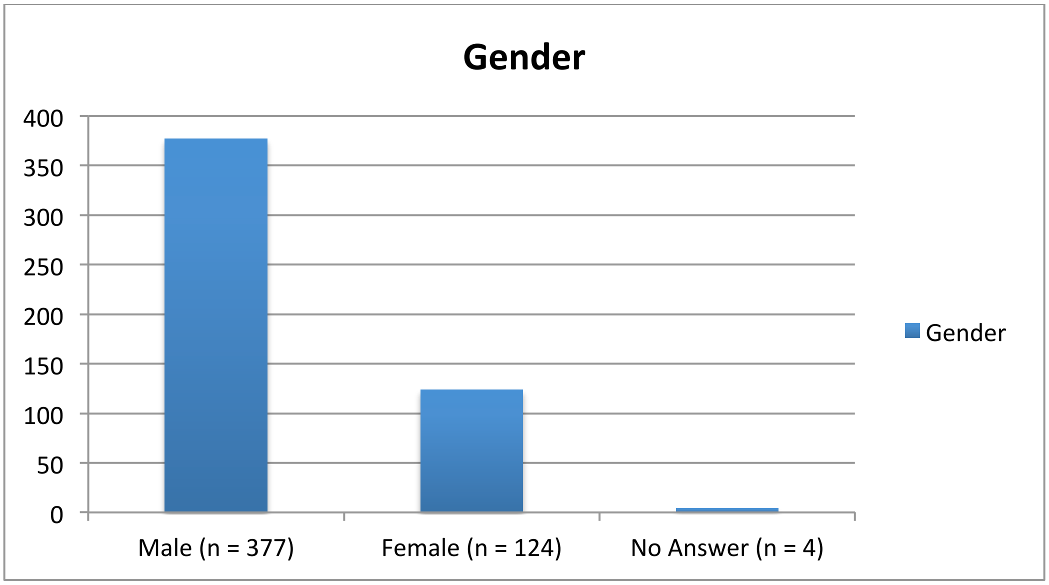

Figure 1. Sample Demographics by Gender

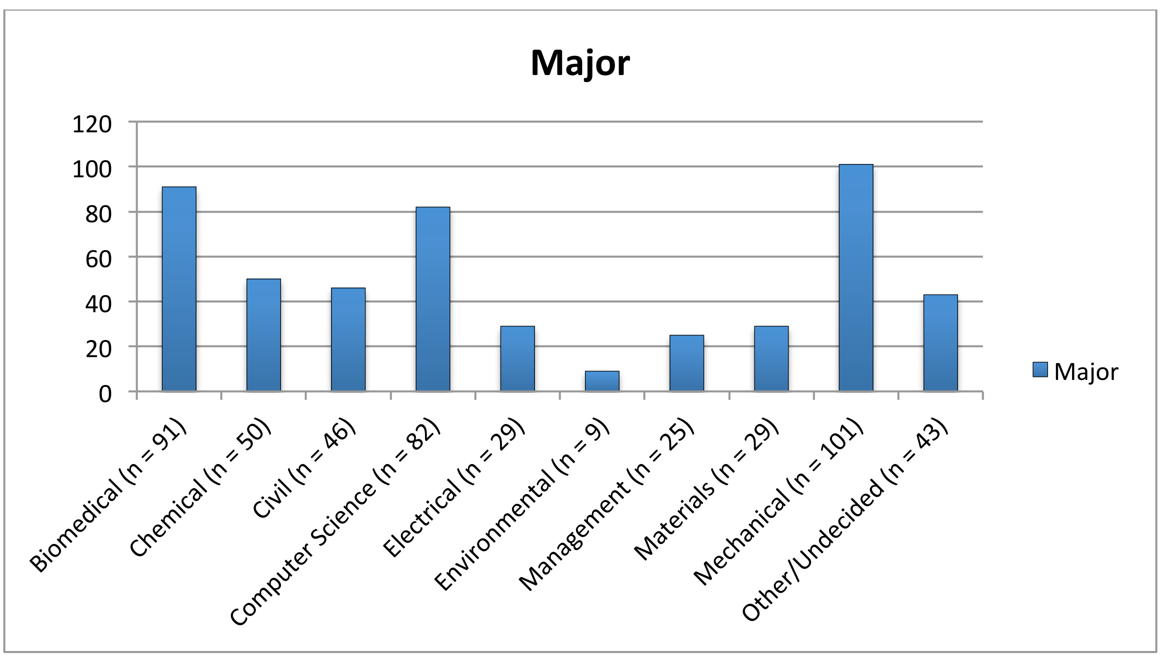

Figure 2. Sample Demographics by Major

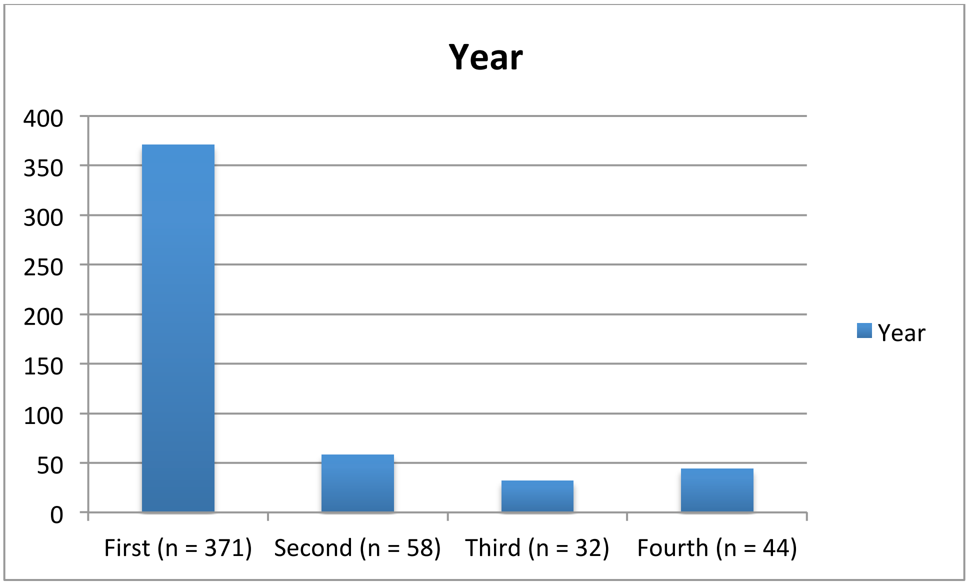

Figure 3. Sample Demographics by Year

Instrumentation

Participants were asked to complete several sets of measures via on-line survey. First, the students were asked to complete a demographic information form. This form includes gender, age, specific engineering major, and level of experience (freshman, sophomore, junior, senior). Second, participants were asked to complete a problem to provide solutions to a general real-world, engineering-related, ill-defined task. Third, participants were asked to complete a set of individual differences measures to be used as potential predictor variables (personality and creative self-efficacy in engineering). Fourth, participants were asked to complete a set of measures of specific academic outcomes (such as learning goals, performance goals, perceived ability in engineering, and academic interest in engineering). Finally, participants were asked to complete a four-item measure to check their knowledge on the questions in the engineering problem. This measure was used as a control variable. In addition, participants had the option to provide their contact information if they want to be entered in a drawing to win one out of four

$25 Amazon gift card (at no point was this personal information associated with any of their responses). For the exact measures, see Appendices A through H.

Measures of Stages of Creative Problem Solving Process

The measures of creative thinking skills were derived from the engineering-relevant multi-stage problem. This problem was created through a multi-step process. First, a panel of several engineering professors created different scenarios involving general engineering problems. Next, the panel reviewed all scenarios with regard to three criteria: (a) real-world applications, (b) relevance to multiple engineering disciplines, and (c) potentially open-ended with room for creativity. Additionally, the problems were checked for clarity and realism. This process led to the selection of one prompt that was used in the study:

> *"I recently moved into an old farm house and I was horrified when I received the bills for the first quarter. The electricity bill was twice what I am used to; I had to pay triple what I was paying in my last place for oil. What can I do?"*

This problem included four stages in which students were asked to write their responses to each stage. Each response for each stage was later rated as part of the measurement of the creative process. Participants were asked to read through the scenario and then assume the role of the responsible engineer for their response. After reading the scenario, students were presented with four questions that led them through the four stages of the creative problem solving process. The questions are:

1. Identify an engineering-related problem that you find in this scenario and explain it in detail in one or two sentences.
2. Think of potential solutions to this problem. List as many different ideas as you can that might solve it.

3. Out of all of your potential solutions, which idea would you select as your best idea that you would choose to implement to solve the problem?
4. Finally, think of how you would validate and carry out your solution. In two or three sentences, explain what your plans for implementation.

The creative problem-solving processes that were targeted for assessment are the following four stages: (a) problem recognition (Question 1), (b) idea generation (Question 2), (c) idea evaluation (Question 3), and (d) solution validation (Question 4).

Scoring Protocol

After data collection, all responses were entered into a spreadsheet computer program. Participants' responses were scored using the Consensual Assessment Technique (Amabile, 1996). According to this method, experts from the relevant field are the best and the most appropriate judges of creativity in the domain (J. C. Kaufman et al., 2009). However, the question of what constitutes an expert is still being studied and debated. Given the difficulty in obtaining high-level experts to serve as raters for a large sample, Kaufman and Baer (2012) proposed the use of quasi-experts – that is, people with experience in the particular field who are clearly above the level of a novice yet who may not have completed the ten years of deliberate practice typically needed to be qualified as an expert (Ericsson, 1996). Studies have shown that advanced students in a field tend to agree at a reasonable level with actual experts (J. C. Kaufman et al., 2013, 2005), and both experts and quasi-experts in the domains of teaching and creativity research also agree with domain experts when judging student work (Baer et al., 2009; J. C. Kaufman et al., 2013).

Consistent with the methodology proposed by Kaufman and Baer (2012) and demonstrated by Kaufman et al. (2013), I used several quasi-experts from within the fields of

education, creativity research, and the domain in question (engineering). Twelve expert and quasi-expert engineers (engineering graduate students and professional engineers from different disciplines) rated the quality of creative problem solving stages (four rated the quality of problem recognition stage; a different four rated the quality of idea generation stage; and four different raters assessed the quality of solution validation stage). In addition, five graduate students in the field of education with expertise in creativity research rated the responses to all four stages for overall creativity. Consistent with past Consensual Assessment Technique work (Amabile, 1996), raters assigned scores to each of the responses based on specific criteria. Raters worked alone and primarily relied on their personal definitions of the concepts of creativity and quality. Inter-rater reliability (consistency among the raters) was evaluated with Cronbach's (1951) coefficient alpha. Cronbach's coefficient alpha is a standard measure of internal consistency and has been used in creativity research as a measure of inter-rater reliability, treating raters as items (see J. C. Kaufman, Plucker, & Baer, 2008). Procedures for scoring the four stages slightly differ. The following sections give more details about how the raters scored each stage.

Question 1—Problem Recognition Stage:

The raters were given a copy of the original problem and specific questions to use as a core basis, along with their expertise, for scoring participants' responses. The specific instructions that raters received for scoring this stage are included in Appendix I. They used a six-point Likert scale (1 = lowest quality, 6 = highest quality) to assess participants' responses based on the quality of the response. Inter-rater reliability was computed using Cronbach's alpha; it was equal to .80, indicating high agreement among the four raters. A "problem recognition" score was thus generated based on the average score across all raters.

Question 2—Idea Generation Stage:

The raters were given a copy of the original problem and specific questions to use as a core basis, along with their expertise, for scoring participants' responses. The specific instructions that raters received are included in Appendix I. As with the first question, they used a six-point Likert scale (1 = lowest quality, 6 = highest quality) to assess participants' responses based on the quality of the response. Participants' responses were listed as multiple ideas. Ideas were first separated into distinct entries when multiple ideas were listed in one thought. This procedure was done because the quality of ideas may vary even when initially merged into one long concept. For example, if a participant wrote "They could install a wood-burning stove or a space-heater, rather than heating their whole house at once, if they're not using every single room," it would be reformatted so that one idea read "They could install a wood-burning stove, rather than heating their whole house at once, if they're not using every single room" and another idea read "They could install a space-heater, rather than heating their whole house at once, if they're not using every single room." Even though they were listed together, these are two distinct ideas that may be of different quality and creativity. The raters then rated every idea generated by the participants. Inter-rater reliability was computed using Cronbach's alpha; it indicated substantial agreement of .778 among the four raters. The scores were averaged across all raters to produce a quality score for each idea, and the scores for all of a participant's ideas were averaged to produce an aggregate score for idea generation.

In addition, traditional divergent thinking scoring was used to produce three additional scores for each participant: fluency, flexibility, and originality. Consistent with the methods outlined by Guilford (1967) and Torrance (1974), all ideas generated by the participants were categorized using the following steps:

1. All responses that were broadly task appropriate (see J. C. Kaufman, Baer, Cole, & Sexton, 2008) were collated into one large list of all of the different responses. The responses were sorted from the most common to most rare, along with the number of times these responses were given.
2. In addition, all ideas generated were categorized:
    a. Two evaluators (different from the raters who assessed students' responses) reviewed the full list of ideas. Each person created a list of possible categories. The two raters met to compare categories. A final list of categories was reached by consensus. A miscellaneous category was also created. Each rater's original category list was kept as well as the final category list for reporting of raters' agreement.
    b. Then using the list of agreed upon categories, the two raters categorized the ideas. These two raters read through the list, and assigned the category. The two raters then met to resolve any differences in how ideas were assigned. Once all items were assigned, the "miscellaneous" category was evaluated to see if some ideas create a new category that did not exist before. Original assignments and final consensus were kept for evaluation of inter-rater agreement. Kappa coefficient (Cohen, 1960, 1968) was computed to assess the inter-rater agreement. Kappa was found to be equal to .912, indicating a strong agreement between the two raters.
3. A participant received credit for every task appropriate response; this number became the fluency score.
4. A participant received credit for every category; this number became the flexibility score.
5. To calculate originality, a cut-off of 10% was used (Plucker, Qian, & Schmalensee, 2014), in which responses given by ten percent or fewer of the sample received one point; and

responses given by more than ten percent were not assigned any points. Each response by every participant was scored for originality such that each original idea was worth one point. After this process was finished, the total number of originality points was then divided by the fluency score (to avoid strong overlap between the two constructs); this new number became the originality percentage score.

Question 3—Idea Evaluation Stage:

For this stage, the participant had chosen his or her best idea. The choice was evaluated as a ratio of the highest possible score. That is, the rater-assigned score of the selected pick was divided by the highest rater-assigned score that would have been possible for each participant. So, for example, if a person chose an idea that was given an average score of “4” by the raters and no other idea was given a higher score, then that person’s score for the Idea Evaluation stage would be 1 (4 divided by 4). If, however, the person chose the same idea given a “4” score but had a different idea that received a “6” then their score for the Idea Evaluation stage would be .667 (4 divided by 6).

Question 4—Solution Validation Stage:

As with the first two questions, the raters were given a copy of the original problem and specific questions to use as a core basis, along with their expertise, for scoring participants’ responses. See Appendix I for the specific instructions that raters received for scoring this stage. They used a six-point scale (1 = lowest quality, 6 = highest quality) to assess participants’ responses based on the quality of the response. Cronbach’s alpha coefficient was then computed; inter-rater reliability was found to be equal to .774, indicating substantial agreement among the four raters. A “solution validation” score was thus generated based on the average score across all raters.

In addition, the raters used a six-point scale (1 = least creative, 6 = most creative) to assess the holistic creativity of each participant's responses to all of the four questions. The specific instructions that raters received are included in Appendix I. A Cronbach's alpha coefficient of .704 indicated substantial agreement among the raters. An overall creativity score was thus generated for each participant.

Overall, each student was assigned several scores: problem recognition quality score, idea generation quality score, idea evaluation quality score, solution validation quality score, and overall creativity score; in addition, there were the three divergent thinking scores: fluency, flexibility, and originality.

Other Basic Measures

Background information. All participants were asked to complete several demographic questions (gender, age) and a set of questions about their professional background (engineering major, year in the program, self-reported GPA).

Knowledge. This scale was created for this study to measure participants' knowledge on the engineering problem. The scale contains 4 items that are intended to measure how familiar a student is with the energy topic and engineering problem solving. Students responded to each statement using a 6-point Likert scale from 1 (not familiar at all) to 6 (very familiar).

Predictors

Ten-Item Big Five Inventory. The 10-item short version of the Big Five Inventory (BFI-10; Rammstedt & John, 2007) is an abbreviated version of the Big Five Inventory (BFI-44; John, Donahue, & Kentle, 1991). It is a self-report measure for assessing the basic personality dimensions of extraversion (e.g., "reserved"), agreeableness (e.g., "generally trusting"), conscientiousness ("does a thorough job"), emotional stability (e.g., "relaxed, handles stress

well”), and openness to experience (e.g., “has an active imagination”; Soto, John, Gosling, & Potter, 2008). Respondents rate the extent to which they agree with self-descriptive statements using a 1 (“strongly disagree”) to 6 (“strongly agree”) response scale. The scale retains significant levels of reliability and validity compared to full-length versions of the personality scale. That is, the correlations between the full version scale (BFI-44) and the 10-item scale for extroversion, emotional stability, conscientiousness, agreeableness, and openness are: .89, .86, .82, .74, and .79, respectively (Rammstedt & John, 2007).

Creative Self-Efficacy in Engineering. The Creative Self-Efficacy in Engineering scale, adapted from Beghetto (2006, 2009) is 6 items that are intended to measure student’s beliefs about their ability to generate novel and useful ideas in engineering and whether they view themselves as having a good imagination to generate solutions to engineering problems. Students respond to each statement using a 6-point Likert scale from 1 (not true) to 6 (very true). The original scale shows good internal consistency (alpha = .86 Beghetto, 2006) and takes only a few minutes to administer.

Outcomes

Learning Goals, Performance Goals, and Perceived Ability in Engineering. This scale is adapted from the Achievement Goals Questionnaire (Elliot & McGregor, 2001), which is a scale that is intended to measure student’s learning goals, performance goals, and perceived ability. Students responded to each statement using a 6-point Likert scale from 1 (strongly disagree) to 6 (strongly agree). The first part is 4 items intended to measure student’s beliefs about their learning goals. The second part is 8 items intended to measure student’s beliefs about their performance goals. The third part is 8 items intended to measure student’s beliefs about their academic ability. The original scale shows good reliability and validity. Cronbach’s alpha

reliability coefficients of the original subscales ranged from .63 to .92, all indicating acceptable internal consistencies (Elliot & McGregor, 2001).

Academic Interest in Engineering. This scale is adapted from the Academic Interest scale (Harackiewicz, Barron, Tauer, Carter, & Elliot, 2000), which is 10 items that are intended to measure student's interest in academic work. Students respond to each statement using a 6-point Likert scale from 1 (strongly disagree) to 6 (strongly agree). The original scale shows good reliability and validity (alpha = .93).

Data Analyses

Research Question 1. Do students across different engineering domains and at different stages of their education demonstrate different patterns of strengths in creative problem solving skills (specifically, problem recognition, idea generation, idea evaluation, and solution validation)?

For the first research question, scores on the four measures of creative problem-solving skills were treated as the dependent variables of interest in a series of analysis of variance tests (ANOVA). The independent variables that were examined in each analysis were the engineering domains (major) and the level of experience (year). In addition, a series of ANOVA tests were conducted in which the divergent thinking measures (fluency, flexibility, and originality percentage) were treated as dependent variables. The independent variables in these analyses were major and year.

Research Question 2. Do individual difference variables (such as gender, personality, and creative self-efficacy in engineering) differentially predict engineering creativity and problem solving quality?

For the second research question a series of multiple regressions were conducted in which the scores from all four measures of creative problem solving were treated as the

dependent variables. The independent variables included gender, extroversion, agreeableness, conscientiousness, emotional stability, openness, creative self-efficacy in engineering, and knowledge. Knowledge was included in these analyses to control for its effect.

Research Question 3. Are different parts of the creative problem solving process associated with specific desired academic outcomes (such as self-reported GPA, engagement with engineering (measured as both learning and performance goals), perceived ability in engineering, and academic engineering interest)?

For the third research question, I conducted a series of multiple regressions in which the dependent variables included academic outcomes such as self-reported overall GPA, self-reported GPA in engineering classes, engagement with engineering (learning goals and performance goals), perceived ability in engineering, and academic engineering Interest. The scores from all four measures of creative problem solving were treated as the independent variables.

Finally, I conducted a path analysis model to further investigate the association between the quality of each stage of the creative problem solving and overall creativity. In addition, given that the responses from the idea generation stage were also scored using divergent thinking techniques, another path analysis model was conducted to explore the interrelationship between the three divergent thinking measures and the idea generation quality score, as well how these four variables predicted the overall creativity.

CHAPTER 4: FINDINGS

Descriptive Statistics

A sample of 505 undergraduate engineering students was recruited from a public northeastern university for this study. Participants completed several sets of measures via on-line survey: (a) demographic information form (gender, age, specific engineering major, and year in the engineering program); (b) a problem to provide solutions to a general real-world, engineering-related, ill-defined task; (c) a four-item measure to check their knowledge related to the specific engineering problem used in the study; (d) a set of individual differences measures (personality and creative self-efficacy in engineering); and (e) specific academic outcomes (such as learning goals, performance goals, perceived ability in engineering, and academic interest in engineering).

The measures of creative thinking skills were derived from the engineering-relevant multi-stage problem. This problem included four stages in which students were asked to write their responses to each stage. Each response for each stage was later rated as part of the measurement of the creative process. The creative problem-solving processes that were targeted for assessment are the following four stages: (a) problem recognition (Question 1), (b) idea generation (Question 2), (c) idea evaluation (Question 3), and (d) solution validation (Question 4). Participants' responses were scored using the Consensual Assessment Technique (Amabile, 1996). As outlined in Chapter 3, this study used several quasi-experts from within the fields of engineering, education, and creativity research to assign scores to each of the responses based on specific criteria. As explained in Chapter 3, raters from within the field of engineering scored each of the four questions for quality, and other raters from within the field of education scored the overall creativity of each participant's responses to all of the four questions. Inter-rater

reliabilities (consistency among the raters) were evaluated with Cronbach's (1951) coefficient alpha; they ranged from .704 to .800, all indicating good inter-rater agreements. Finally, raters' scores were averaged to generate participants' scores for each stage as well as an overall creativity score. As a result, each student was assigned several scores: problem recognition quality score, idea generation quality score, idea evaluation quality score, solution validation quality score, and overall creativity; in addition, there were the three divergent thinking scores: fluency, flexibility, and originality. Table 4.1 gives the descriptive analyses of all the variables. Table 4.2 gives the correlation matrix of the variables.

The nine engineering majors in the survey were clustered under the major engineering organizations identified by the National Science Foundation/Directorate for Engineering—Chemical, Bioengineering, Environmental, and Transport Systems (CBET); Civil, Mechanical, and Manufacturing Innovation (CMMI); and Electrical, Communications, and Cyber Systems (ECCS) (National Science Foundation, n. d.). The fourth group identified as "Other" included participants who reported undecided major; this group was deleted from the analyses that had major as a variable. Given the large number of first year students compared to the number of second, third, and fourth year students, year of students was categorized as "First Year" and "Advanced." Tables J.1 through J.3 in Appendix J give the frequencies of the participants by gender, major, and year, respectively.

Tables J.4 through J.19 in Appendix J give the difference in GPA, engineering GPA, knowledge, creative self-efficacy, learning goals, performance goals, perceived ability, and interest by major and by year.

Table 4.1. *Descriptive Statistics*

	N	Minimum	Maximum	Mean	Std. Deviation
Knowledge	505	1.00	6.00	4.00	1.06
Extroversion	502	1.00	6.00	3.86	1.09
Agreeableness	502	1.00	6.00	4.16	.92
Conscientiousness	502	1.50	6.00	4.28	.88
Emotional Stability	502	1.00	6.00	3.94	1.07
Openness to Experience	502	1.00	6.00	4.27	.99
Creative Self-Efficacy	503	1.00	6.00	4.54	.88
Problem Recognition	505	1.00	5.50	3.14	.86
Idea Generation	505	1.58	5.25	3.83	.60
Idea Evaluation	505	.21	1.00	.90	.14
Solution Validation	505	1.00	5.25	2.63	.80
Overall Creativity	505	1.00	5.60	2.90	.82
Fluency	505	1.00	20.00	4.74	2.65
Flexibility	505	1.00	8.00	2.97	1.35
Originality Percentage	505	.00	1.00	.52	.28
Learning Goals	504	2.50	6.00	5.16	.68
Performance Goals	504	1.00	6.00	4.24	1.07
Perceived Ability	503	1.63	6.00	4.59	.74
Interest	503	1.50	6.00	4.82	.78
Overall GPA	505	2.00	4.00	3.31	.42
Engineering GPA	505	1.50	4.00	3.35	.50

Table 4.2. *Correlation Among Variables*

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. Extroversion	1.000										
2. Agreeableness	.142**	1.000									
3. Conscientiousness	.092*	.146**	1.000								
4. Emotional Stability	.282**	.155**	.150**	1.000							
5. Openness	.131**	.032	.151**	.064	1.000						
6. Creative Self-Efficacy	.153**	.070	.140**	.219**	.266**	1.000					
7. Knowledge	.041	.045	.094*	.090*	.128**	.494**	1.000				
8. Problem Recognition	.005	-.023	.039	.042	-.001	.054	.078	1.000			
9. Idea Generation	-.048	.025	.044	.033	.002	.083	.186**	.285**	1.000		
10. Idea Evaluation	.004	.114	.043	-.009	.015	-.003	.075	-.006	.188**	1.000	
11. Solution Validation	.015	.082	.074	.041	.013	.085	.128**	.216**	.133**	.051	1.000
12. Overall Creativity	.008	.030	.088*	.030	.120**	.134**	.221**	.223**	-.042	-.199**	.368*
13. Fluency	-.016	-.005	.067	.073	.033	.160**	.271**	.164**	.019	-.138**	.228**
14. Flexibility	-.033	-.036	.022	.015	.061	.150**	.244**	.160**	-.069	-.187**	.251**
15. Originality Percentage	-.026	-.035	.000	-.017	-.013	-.055	-.099*	.027	-.127**	-.084	-.059
16. Learning Goals	.058	.103*	.296**	.140**	.181**	.399**	.214**	.088*	.102*	.002	.149**
17. Performance Goals	.026	-.100*	.025	-.111*	.002	.130**	.083	-.068	-.058	-.017	-.064
18. Perceived Ability	.043	.024	.231**	.223**	.087	.589**	.370**	.072	.077	-.031	.072
19. Interest	.047	.166**	.198**	.091*	.088*	.395**	.254**	.008	.065	.062	.155**
20. Overall GPA	-.015	-.064	.182**	.031	-.034	.072	.041	-.020	-.009	.014	-.034
21. Engineering GPA	.021	-.012	.173**	.067	.000	.077	.043	-.001	-.004	.027	.031

Correlation Among Variables (Continued)

	12.	13.	14.	15.	16.	17.	18.	19.	20.	21.
12. Overall Creativity	1.000									
13. Fluency	.595**	1.000								
14. Flexibility	.550**	.776**	1.000							
15. Originality Percentage	.188**	.125**	.010	1.000						
16. Learning Goals	.150**	.151**	.123**	.004	1.000					
17. Performance Goals	-.005	-.006	-.038	.032	.242**	1.000				
18. Perceived Ability	.168**	.211**	.209**	-.026	.433**	.059*	1.000			
19. Interest	.127**	.112*	.092*	.003	.549**	.095*	.490**	1.000		
20. Overall GPA	.045	.096*	.091*	.072	.208**	.001	.408**	.186**	1.000	
21. Engineering GPA	.053	.079	.099*	.058	.208**	-.012	.408**	.228**	.814**	1.000

Note. * $p < .05$; ** $p < .01$

Research Question 1

Research question 1 asked if students across different engineering domains and at different stages of their education would demonstrate different patterns of strengths in creative problem solving skills (specifically, problem recognition, idea generation, idea evaluation, and solution validation).

A series of two-way ANOVAs were computed on the four stages of creative problem solving as well as on overall creativity. The independent variables in each of the models were the engineering major (3 levels: CBET, CMMI, ECCS) and the year in the program (2 levels: First, Advanced). In addition, a series of two-way ANOVAs were computed on the divergent thinking measures (fluency, flexibility, and originality percentage) where the independent variables included major and year.

Problem Recognition

A 3x2 ANOVA was computed on problem recognition scores with major and year and the interaction major*year. Major was a significant factor with low effect size given by partial eta squared (.01 is small, .06 is medium, and .14 is large; Cohen, 1988, pp. 284–287), [F (2, 456) = 5.510, p = .004, η^2 = .024] on problem recognition scores. Post-hoc test was conducted and revealed that majors in Electrical, Communications, and Cyber Systems (ECCS, n = 136, M = 2.96, SD = .84) had significantly lower scores on problem recognition than majors in Chemical, Bioengineering, Environmental, and Transport Systems (CBET, n = 179, M = 3.24, SD = .81) and than majors in Civil, Mechanical, and Manufacturing Innovation (CMMI, n = 147, M = 3.22, SD = .91). Year was also a significant factor with a low effect size as assessed by partial eta squared [F (1, 456) = 6.172, p = .013, η^2 = .013]. Students in their first year had significantly lower scores on problem recognition (n = 371, M = 3.08, SD = .84) than students in their

advanced years (second, third, or fourth year) (n = 134, M = 3.33, SD = .90). The interaction term was not significant [F (2, 456) = .892, p = .410].

Idea Generation

A 3x2 ANOVA was computed on idea generation scores with major and year and the interaction major*year. Major was not a significant factor [F (2, 456) = 2.029, p = .133] on idea generation scores. Year was not a significant factor either [F (1, 456) = 3.817, p = .051]. The interaction term was not significant as well [F (2, 456) = 2.118, p = .122].

Idea Evaluation

A 3x2 ANOVA was computed on idea evaluation scores with major and year and the interaction major*year. Major was not a significant factor [F (2, 456) = .877, p = .417] on idea evaluation scores. Year was not a significant factor either [F (1, 456) = 1.603, p = .206]. The interaction term was not significant as well [F (2, 456) = .358, p = .699].

Solution Validation

A 3x2 ANOVA was computed on solution validation scores with major and year and the interaction major*year. Major was not a significant factor [F (2, 456) = .028, p = .972] on solution validation scores. Year was not a significant factor either [F (1, 456) = .011, p = .917]. The interaction term was not significant as well [F (2, 456) = 1.690, p = .186].

Overall Creativity

A 3x2 ANOVA was computed on overall creativity scores with major and year and the interaction major*year. Major was a significant factor with low effect size given by partial eta squared [F (2, 456) = 4.287, p = .014, η^2 = .018] on overall creativity scores. Post-hoc test was conducted and revealed that majors in Chemical, Bioengineering, Environmental, and Transport Systems (CBET, n = 179, M = 2.96, SD = .81) had higher scores on overall creativity than

majors in Civil, Mechanical, and Manufacturing Innovation (CMMI, n = 147, M = 2.94, SD = .84), which in turn had higher scores than majors in Electrical, Communications, and Cyber Systems (ECCS, n = 136, M = 2.78, SD = .82). Year was also a significant factor with a low effect size [F (1, 456) = 8.364, p = .004, η^2 = .018]. That is, students in their first year had significantly lower scores on overall creativity (n = 371, M = 2.82, SD = .77) than students in their advanced years (second, third, or fourth year) (n = 134, M = 3.12, SD = .92). The interaction term was significant as well with a low effect size [F (2, 456) = 4.611, p = 010, η^2 = .020]. That is, students in their first year differed in their creativity scores from students in their advanced year depending on which major they were in. A post-hoc test was conducted to compare the subgroups. As shown in Figure 4, advanced students with a CBET major had notably higher overall creativity scores than CBET first year students; advanced students in other majors did not show as large a discrepancy. Table 4.3 shows the results of these comparisons in more detail.

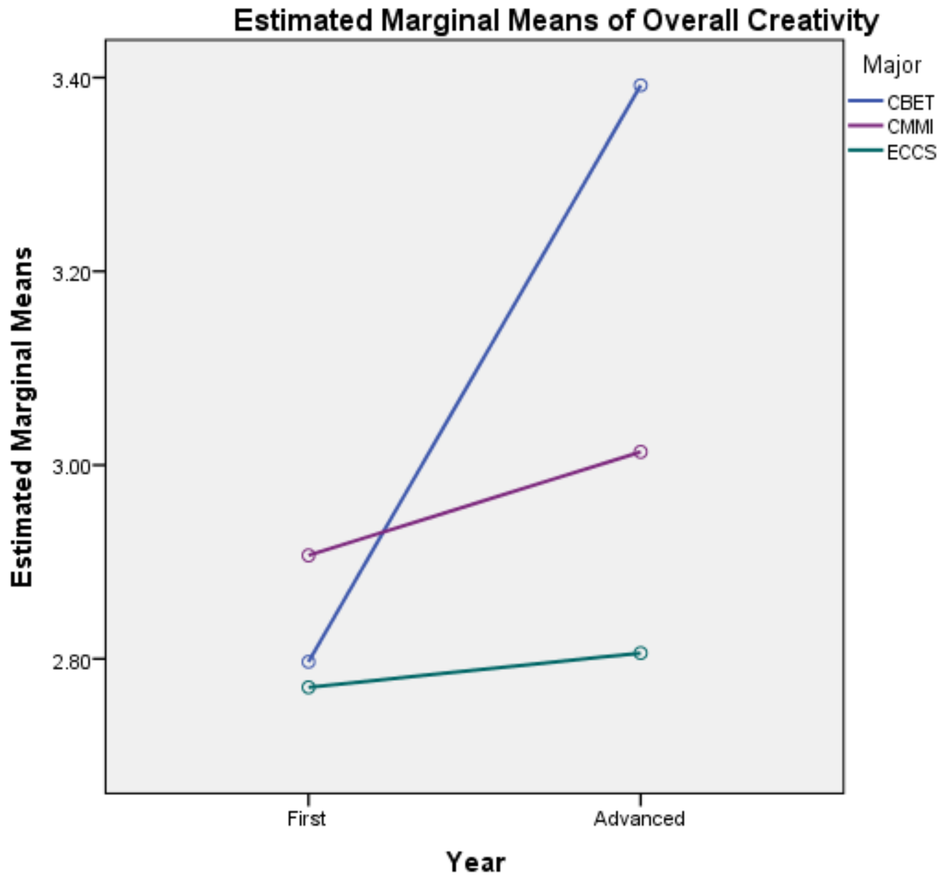

Figure 4. Major*Year Interaction Effect on Overall Creativity

Table 4.3. *Major*Year Post-Hoc Comparisons (Dependent Variable: Overall Creativity)*

				95% Confidence Interval	
Major	**Year**	**Mean**	**Std. Error**	**Lower Bound**	**Upper Bound**
CBET	**First**	2.797	.071	2.657	2.937
	Advanced	3.392	.114	3.167	3.617
CMMI	**First**	2.907	.080	2.750	3.063
	Advanced	3.014	.122	2.774	3.253
ECCS	**First**	2.771	.080	2.613	2.928
	Advanced	2.806	.139	2.533	3.078

Note. CBET: Chemical, Bioengineering, Environmental, & Transport Systems; CMMI: Civil, Mechanical, & Manufacturing Innovation; ECCS: Electrical, Communications, & Cyber Systems.

Divergent Thinking Measures

A 3x2 ANOVA was computed on fluency scores with major and year and the interaction major*year. Major was not a significant factor [F (2, 456) = .751, p = .473]. Year was a significant factor with a low effect size [F (1, 456) = 12.261, p = .001, η^2 = .026]. Students in their first year had significantly lower scores on Fluency (n = 371, M = 4.44, SD = 2.31) than students in their advanced years (second, third, or fourth year) (n = 134, M = 5.57, SD = 3.30). The interaction term was not significant [F (2, 456) = 1.042, p = .354].

A 3x2 ANOVA was computed on flexibility scores with major and year and the interaction major*year. Major was not a significant factor [F (2, 456) = .100, p = .905]. Year was a significant factor with a low effect size [F (1, 456) = 10.854, p = .001, η^2 = .023]. Students in their first year had significantly lower scores on flexibility (n = 371, M = 2.83, SD = 1.28) than students in their advanced years (second, third, or fourth year) (n = 134, M = 3.37, SD = 1.45). The interaction term was not significant [F (2, 456) = .565, p = .569].

A 3x2 ANOVA was computed on originality percentage scores with major and year and the interaction major*year. Major was not a significant factor [F (2, 456) = .573, p = .564]. Year was not a significant factor either [F (1, 456) = 1.294, p = .256]. The interaction term was not significant [F (2, 456) = 1.439, p = .238].

Table 4.4 summarizes the above-mentioned ANOVA results.

Table 4.4. *ANOVA Results*

Dependent Variable	**Factor**	**F**	**P**	η^2
Problem Recognition	**Major**	**5.510**	**.004**	**.024**
	Year	**6.172**	**.013**	**.013**
	Interaction	.892	.410	.004
Idea Generation	Major	2.029	.133	.009
	Year	3.817	.051	.008
	Interaction	2.118	.122	.009
Idea Evaluation	Major	.877	.417	.004
	Year	1.603	.206	.004
	Interaction	.358	.699	.002
Solution Validation	Major	.028	.972	.000
	Year	.011	.917	.000
	Interaction	1.690	.186	.007
Overall Creativity	**Major**	**4.287**	**.014**	**.018**
	Year	**8.364**	**.004**	**.018**
	Interaction	**4.611**	**.010**	**.020**
Fluency	Major	.751	.473	.003
	Year	**12.261**	**.001**	**.026**
	Interaction	1.042	.354	.005
Flexibility	Major	.100	.905	.000
	Year	**10.854**	**.001**	**.023**
	Interaction	.565	.569	.002
Originality Percentage	Major	.573	.564	.003
	Year	1.294	.256	.003
	Interaction	1.439	.238	.006

Research Question 2

Research Question 2 asked how individual difference variables (such as gender, personality, and creative self-efficacy in engineering) might predict engineering creativity and problem solving quality.

A series of multiple linear regressions were conducted on the four stages of creative problem solving as well as on the overall creativity. The independent variables in each regression model were gender, the Big Five Personality factors (extroversion, agreeableness, conscientiousness, emotional stability, and openness), creative self-efficacy, and knowledge. Knowledge was included to control for its effect.

A multiple linear regression was also conducted on overall creativity where independent variables included the quality of problem solving stages to investigate the predictive relationships between each stage and overall creativity.

Problem Recognition

A multiple regression analysis (n = 496) was conducted to test if specific individual difference variables significantly predicted engineering students' scores on the first stage of creative problem solving (problem recognition). Problem recognition was treated as the dependent variable. The independent variables included gender, extroversion, agreeableness, conscientiousness, openness, emotional stability, creative self-efficacy, and knowledge. Results showed that none of the independent variables significantly predicted problem recognition scores.

Idea Generation

A multiple regression analysis (n = 496) was conducted to test if specific individual difference variables significantly predicted engineering students' scores on the second stage of

creative problem solving (idea generation). Idea generation was treated as the dependent variable. The independent variables included gender, extroversion, agreeableness, conscientiousness, openness, emotional stability, creative self-efficacy, and knowledge. Results showed that only knowledge significantly predicted idea generation [$\beta = .111$, $t(486) = 3.864$, $p < .001$]. The model explained a significant proportion of variance in idea generation scores [$R^2 = .045$, $F(8, 486) = 2.838$, $p = .004$].

Idea Evaluation

A multiple regression analysis ($n = 496$) was conducted to test if specific individual difference variables significantly predicted engineering students' scores on the third stage of creative problem solving (idea evaluation). Idea evaluation was treated as the dependent variable. The independent variables included gender, extroversion, agreeableness, conscientiousness, openness, emotional stability, creative self-efficacy, and knowledge. Results showed that only agreeableness significantly predicted idea evaluation [$\beta = .017$, $t(486) = 2.423$, $p = .016$].

Solution Validation

A multiple regression analysis ($n = 496$) was conducted to test if specific individual difference variables significantly predicted engineering students' scores on the fourth stage of creative problem solving (solution validation). Solution validation was treated as the dependent variable. The independent variables included gender, extroversion, agreeableness, conscientiousness, openness, emotional stability, creative self-efficacy, and knowledge. Results showed that only knowledge significantly predicted solution validation scores [$\beta = .080$, $t(486) = 2.069$, $p = .039$].

Overall Creativity

A multiple regression analysis (n = 496) was conducted to test if specific individual difference variables significantly predicted engineering students' overall creativity. Overall creativity was treated as the dependent variable. The independent variables included gender, extroversion, agreeableness, conscientiousness, openness, emotional stability, creative self-efficacy, and knowledge. Results showed that knowledge significantly predicted overall creativity scores [$\beta = .163$, $t(486) = 4.160$, $p < .001$]. Openness was of marginal significance to predict overall creativity [$\beta = .073$, $t(486) = 1.907$, $p = .057$]. The model explained a significant proportion of variance in overall creativity scores [$R^2 = .061$, $F(8, 486) = 3.977$, $p < .001$].

Table 4.5 summarizes the significant results mentioned above.

Table 4.5. *Regression Results of Creative Measures*

Dependent Variable	Independent Variable	β	t	P
Problem Recognition	Gender	.008	.082	.935
	Extroversion	-.005	-.127	.899
	Agreeableness	-.034	-.791	.429
	Conscientiousness	.037	.809	.419
	Emotional Stability	.037	.929	.353
	Openness	-.019	-.471	.638
	Creative Self-Efficacy	.022	.413	.680
	Knowledge	.062	1.475	.141
Idea Generation	Gender	.040	.617	.538
	Extroversion	-.037	-1.420	.156
	Agreeableness	.009	.315	.753
	Conscientiousness	.024	.751	.453
	Emotional Stability	.018	.666	.506
	Openness	-.010	-.342	.733
	Creative Self-Efficacy	.000	.014	.989
	Knowledge	**.111**	**3.864**	**< .001**
Idea Evaluation	Gender	.016	1.042	.298
	Extroversion	-.001	-.221	.825
	Agreeableness	**.017**	**2.423**	**.016**
	Conscientiousness	.004	.519	.604
	Emotional Stability	-.002	-.238	.812
	Openness	.000	.062	.951
	Creative Self-Efficacy	-.007	-.843	.399
	Knowledge	.012	1.807	.071

Regression Results of Creative Measures (Continued)

Dependent Variable	Independent Variable	β	t	P
Solution Validation	Gender	-.095	-1.089	.277
	Extroversion	.006	-.182	.856
	Agreeableness	.063	1.596	.111
	Conscientiousness	.053	1.262	.207
	Emotional Stability	-.006	-.160	.873
	Openness	-.012	-.319	.750
	Creative Self-Efficacy	.000	.174	.862
	Knowledge	**.080**	**2.069**	**.039**
Overall Creativity	Gender	.012	.140	.888
	Extroversion	-.019	-.542	.588
	Agreeableness	.014	.357	.722
	Conscientiousness	.043	.992	.322
	Emotional Stability	.002	.042	.966
	Openness	.073	1.907	.057
	Creative Self-Efficacy	.000	-.007	.995
	Knowledge	**.163**	**4.160**	**< .001**

Overall Creativity and Creative Problem Solving Stages

A multiple regression analysis (*n* = 505) was conducted to test if the quality of any of the stages of creative problem solving significantly predicted engineering students' overall creativity. Overall creativity was treated as the dependent variable. The independent variables included the scores on the four creative problem solving stages: problem recognition quality, idea generation quality, idea evaluation quality, and solution validation quality.

All four quality scores significantly predicted overall creativity scores, as follows: problem recognition [$\beta = .177$, $t(499) = 4.343$, $p < .001$], idea generation [$\beta = -.183$, $t(499) = -3.167$, $p = .002$], idea evaluation [$\beta = -.330$, $t(499) = -3.752$, $p < .001$], and solution validation [$\beta = .335$, $t(499) = 7.823$, $p < .001$]. The model explained a significant proportion of variance in overall creativity scores [$R^2 = .198$, $F(4, 499) = 30.856$, $p < .001$], as can be seen in Table 4.6.

Table 4.6. *Creativity and Creative Problem Solving Stages*

Dependent Variable	**Independent Variable**	**β**	**t**	**P**
Creativity	Problem Recognition Quality	.177	4.343	< .001
	Idea Generation Quality	-.183	-3.167	.002
	Idea Evaluation Quality	-.330	-3.752	< .001
	Solution Validation Quality	.335	7.823	< .001

Research Question 3

Research Question 3 asked if different parts of the creative problem solving process would be associated with specific desired academic outcomes: self-reported GPA, self-reported engineering GPA, engagement with engineering (as measured with both learning and performance goals), perceived ability in engineering, and academic engineering interest.

A series of multiple linear regressions were conducted on engineering undergraduates' self-reported GPA, engineering GPA, learning goals, performance goals, perceived ability, and interest. The independent variables in each regression model were the quality scores from each stage of the creative problem solving process and overall creativity.

GPA

A multiple regression analysis (n = 505) was conducted to test if the quality of specific parts of the creative problem solving process or overall creativity significantly predicted engineering students' self-reported overall GPA. Overall GPA was treated as the dependent variable. The independent variables included problem recognition, idea generation, idea evaluation, solution validation, and overall creativity. Results showed that none of the independent variables significantly predicted students' GPA.

Engineering GPA

A multiple regression analysis (n = 505) was conducted to test if the quality of specific parts of the creative problem solving process or overall creativity significantly predicted engineering students' self-reported engineering GPA. Engineering GPA was treated as the dependent variable. The independent variables included problem recognition, idea generation, idea evaluation, solution validation, and overall creativity. Results showed that none of the independent variables significantly predicted students' engineering GPA.

Learning Goals

A multiple regression analysis (n = 504) was conducted to test if the quality of specific parts of the creative problem solving process or overall creativity significantly predicted learning goals. Learning goals was treated as the dependent variable. The independent variables included problem recognition, idea generation, idea evaluation, solution validation, and overall creativity.

Results showed that only overall creativity significantly predicted learning goals [β = .097, t(497) = 2.380, p = .018]. Although other independent variables did not reach significance, idea generation and solution validation were marginally significant, [β = .101, t(497) = 1.887, p = .060], [β = .097, t(497) = 1.871, p = .062], respectively. The model explained a significant proportion of variance in problem recognition scores [R^2 = .042, F(5, 497) = 4.332, p = .001].

Performance Goals

A multiple regression analysis (n = 504) was conducted to test if the quality of specific parts of the creative problem solving process or overall creativity significantly predicted performance goals. Performance goals was treated as the dependent variable. The independent variables included problem recognition, idea generation, idea evaluation, solution validation, and overall creativity. Results showed that none of the independent variables were significantly associated with students' performance goals.

Perceived Ability

A multiple regression analysis (n = 503) was conducted to test if the quality of specific parts of the creative problem solving process or overall creativity significantly predicted perceived ability. Perceived ability was treated as the dependent variable. The independent variables included problem recognition, idea generation, idea evaluation, solution validation, and overall creativity.

Results showed that only overall creativity was significantly associated with perceived ability [β = .150, $t(496) = 3.366$, p = .001]. The model explained a significant proportion of variance in problem recognition scores [R^2 = .035, $F(5, 496) = 3.654$, p = .003].

Interest in Engineering

A multiple regression analysis (n = 503) was conducted to test if the quality of specific parts of the creative problem solving process or overall creativity significantly predicted interest in engineering. Interest was treated as the dependent variable. The independent variables included problem recognition, idea generation, idea evaluation, solution validation, and overall creativity.

Results showed that solution validation and overall creativity were significantly associated with interest [β = .113, $t(496) = 2.397$, p = .017], [β = .108, $t(496) = 2.317$, p = .021], respectively. The model explained a significant proportion of variance in problem recognition scores [R^2 = .040, $F(5, 496) = 4.177$, p = .001].

Table 4.7 summarizes the results of the multiple regression analyses explained in the previous paragraphs.

Table 4.7. *Regression Results of Academic Outcomes*

Dependent Variable	**Independent Variable**	***β***	**t**	**P**
Overall GPA	Problem Recognition	-.013	-.547	.584
	Idea Generation	.003	.085	.932
	Idea Evaluation	.098	.691	.490
	Solution Validation	-.031	-1.209	.227
	Overall Creativity	.040	1.587	.113
Engineering GPA	Problem Recognition	-.009	-.312	.755
	Idea Generation	-.005	-.137	.891
	Idea Evaluation	.144	.851	.395
	Solution Validation	.007	.232	.817
	Overall Creativity	.037	1.198	.231
Learning	Problem Recognition	.013	.350	.727
	Idea Generation	.101	1.887	.060
	Idea Evaluation	.023	.103	.918
	Solution Validation	.077	1.871	.062
	Overall Creativity	**.097**	**2.380**	**.018**
Performance	Problem Recognition	-.065	-1.080	.281
	Idea Generation	-.060	-.698	.486
	Idea Evaluation	-.026	-.071	.944
	Solution Validation	-.077	-1.176	.240
	Overall Creativity	.034	.524	.601
Perceived Ability	Problem Recognition	.010	.241	.809
	Idea Generation	.103	1.769	.078
	Idea Evaluation	-.069	-.280	.779
	Solution Validation	-.003	-.056	.955
	Overall Creativity	**.150**	**3.366**	**.001**
Interest	Problem Recognition	-.055	-1.282	.200
	Idea Generation	.074	1.202	.230
	Idea Evaluation	.411	1.537	.125
	Solution Validation	**.113**	**2.397**	**.017**
	Overall Creativity	**.108**	**2.317**	**.021**

Path Analysis of Quality of Creative Problem Solving Stages and Overall Creativity

A path analysis model was conducted to further investigate the predictive relationships among the four measures of creative problem solving stages (problem recognition quality, idea generation quality, idea evaluation quality, and solution validation quality) and overall creativity.

Figure 5 provides a visual representation of the results of this path model (all path coefficients represented in the model are standardized estimates).

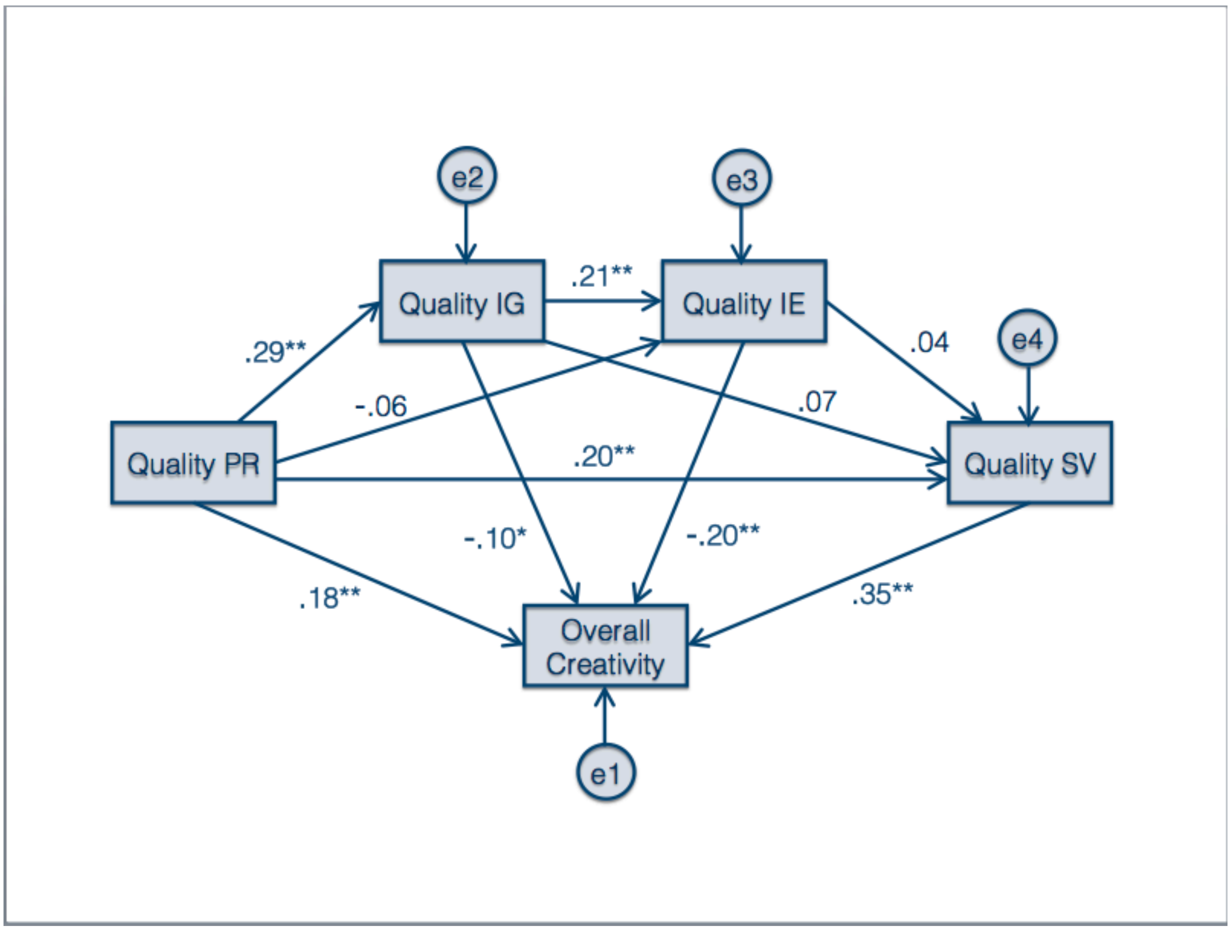

Figure 5. A Path Model of Creative Problem Solving Stages and Overall Creativity

The findings of the above path model reinforce the results found in the multiple linear regressions explained earlier in this chapter (Table 4.8 represents the path coefficients of the

model). However, the findings of this path model offer more details about the indirect predictive relationships between creative problem solving stages and overall creativity. For example, the problem recognition has a significant direct effect on overall creativity (.18), and other indirect effects through idea generation, idea evaluation, and solution validation. The total effect of problem recognition stage on the overall creativity can be calculated by the sum of all direct and indirect effects, where each indirect effect is estimated as the product of all direct effects of that path (Kline, 2005). Table 4.9 shows all of the direct and indirect effects of the quality scores of creative problem solving stages on overall creativity as well as the total effects.

Table 4.8. *Path Coefficients for a Path Model of Creative Problem Solving Stages and Overall Creativity*

Parameter	**Overall Creativity**
Direct Effects	
Quality PR → Quality IG	**.29****
Quality PR → Quality IE	-.06
Quality PR → Quality SV	**.20****
Quality IG → Quality IE	**.21****
Quality IG → Quality SV	.07
Quality IE → Quality SV	.04
Quality PR → Overall Creativity	**.18****
Quality IG → Overall Creativity	**-.10****
Quality IE → Overall Creativity	**-.20****
Quality SV → Overall Creativity	**.35****

Table 4.9. *Effects Decomposition for a Path Model of Creative Problem Solving Stages and Overall Creativity*

Causal Variable	Overall Creativity Standardized Estimates
Problem Recognition Quality	
Direct Effect (PR→Creativity)	.29
Indirect Effect 1 (PR→IG→Creativity)	(.29)(-.10) = -.029
Indirect Effect 2 (PR→IE→Creativity)	(-.06)(-.20) = .012
Indirect Effect 3 (PR→SV→Creativity)	(.20)(.35) = .07
Indirect Effect 4 (PR→IG→IE→Creativity)	(.29)(.21)(-.20) = -.0121
Indirect Effect 5 (PR→IG→SV→Creativity)	(.29)(.07)(.35) = .002
Indirect Effect 6 (PR→IE→SV→Creativity)	(-.06)(.04)(.35) = -.00084
Indirect Effect 7 (PR→IG→IE→SV→Creativity)	(.29)(.21)(.04)(.35) = .00085
Total Effect	**.332**
Idea Generation Quality	
Direct Effect (IG→Creativity)	-.10
Indirect Effect 1 (IG→IE→Creativity)	(.21)(-.20) = -.042
Indirect Effect 2 (IG→SV→Creativity)	(.07)(.35) = .0245
Indirect Effect 3 (IG→IE→SV→Creativity)	(.21)(.04)(.35) = 0.0029
Total Effect	**-.115**
Idea Evaluation Quality	
Direct Effect (IE→Creativity)	-.20
Indirect Effect 1 (IE→SV→Creativity)	(.04)(.35) = .014
Total Effect	**-.186**
Solution Validation Quality	
Direct Effect (SV→Creativity)	.35
Total Effect	**.35**

Path Analysis of Divergent Thinking Measures and Overall Creativity

Another path analysis model was conducted to closely investigate the second stage of the creative problem solving process (idea generation). The model examined the interrelationships between the quality score of idea generation and the three divergent thinking measures (fluency, flexibility, and originality percentage), as well as their predictive relationships with overall creativity. Year and domain-specific knowledge were included in the model to control for their effects on overall creativity.

Figure 6 provides a visual representation of the results of this path model (all path coefficients represented in the model are standardized estimates).

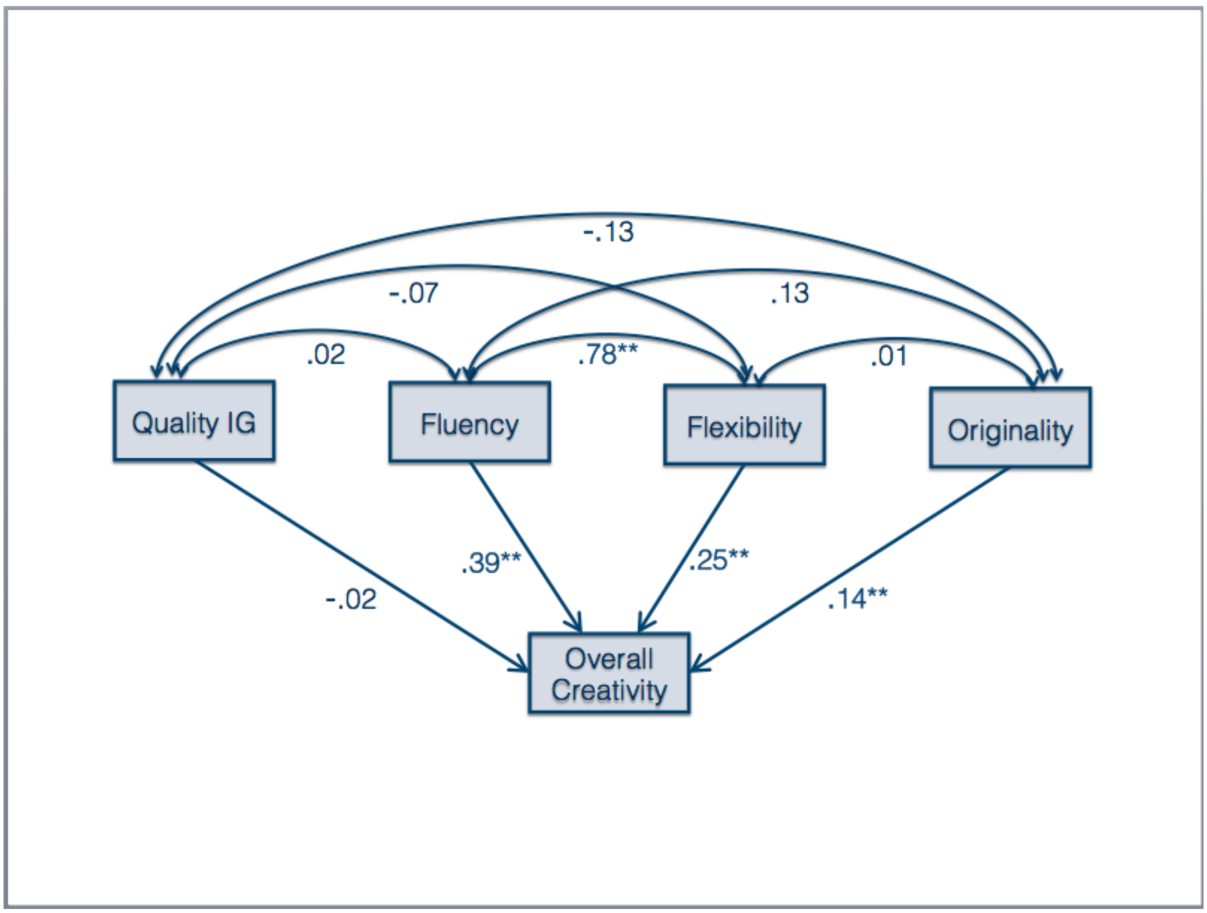

Figure 6. A Path Model of Divergent Thinking Measures and Overall Creativity

Findings of the above path model show that each of the divergent thinking measures (fluency, flexibility, and originality percentage) significantly predicted overall creativity. The standardized path coefficients are .39, .25, and .14 for fluency, flexibility, and originality percentage, respectively. The correlations between the specific divergent thinking measures did not reach significance, except the correlation between fluency and flexibility (.78). The associations between the quality of idea generation and divergent thinking measures were not significant. Table 4.10 represents the path coefficients and the correlation coefficients of the model.

Table 4.10. *Path Coefficients for a Path Model of Divergent Thinking Measures and Overall Creativity*

Parameter	**Overall Creativity**
Direct Effects	
Quality IG → Overall Creativity	-.04
Fluency → Overall Creativity	**.39****
Flexibility → Overall Creativity	**.25****
Originality → Overall Creativity	**.14****
Covariances	
IG ↔ Fluency	.02
IG ↔ Flexibility	-.07
IG ↔ Originality Percentage	-.13
Fluency ↔ Flexibility	**.78****
Fluency ↔ Originality Percentage	.13
Flexibility ↔ Originality Percentage	.01

CHAPTER 5: DISCUSSION AND IMPLICATIONS

This chapter presents a summary of the study findings and conclusions drawn from the findings presented in Chapter 4. Implications, limitations, and directions for future research are discussed as well.

The issue of the creative problem solving processes in postsecondary engineering education has yet to be fully studied, with research being limited in this area. The purpose of this dissertation was to investigate the creative problem solving process within engineering education. In particular, this study examined the way that the quality of different creative problem solving skills (specifically, problem recognition, idea generation, idea evaluation, and solution validation) and overall creativity might affect some desired academic outcomes (overall GPA, engineering GPA, learning goals, performance goals, perceived ability, and interest) while also taking into consideration the effect of individual difference variables (gender, major, year in the engineering program, personality, and creative self-efficacy in engineering).

This quantitative research was designed to respond to the following broad questions:

1. Do students across different engineering domains and at different stages of their education demonstrate different patterns of strengths in creative problem solving skills (specifically, problem recognition, idea generation, idea evaluation, and solution validation)?
2. Do individual difference variables (such as gender, personality, and creative self-efficacy in engineering) differentially predict engineering creativity and problem solving quality?
3. Are different parts of the creative problem solving process associated with specific desired academic outcomes (such as self-reported GPA, engagement with engineering (measured as with both learning and performance goals), perceived ability in engineering, and academic engineering interest)?

Hypotheses proposed for the research questions were rooted in the general creativity literature. The hypotheses are:

Hypothesis 1: Differences will be observed among students in different engineering majors with regard to their problem solving skills.

Hypothesis 2: Differences will also be observed among engineering students in different levels (year in the engineering program) with regard to their problem solving skills.

Hypothesis 3: Individual differences variables will predict some percentage of the quality and creativity of engineering students' creative problem solving.

Hypothesis 4: Creative problem solving skills will be associated with academic outcomes, such as engagement, perceived ability, and academic interest in engineering.

Summary of Findings

In a series of quantitative analyses, engineering students' scores on the first stage of creative problem solving (problem recognition quality) were found to vary based on engineering major and year in the engineering program. However, scores on the other creative problem solving stages (idea generation quality, idea evaluation quality, and solution validation quality) did not vary by major or by year.

Overall creativity scores were found to vary by major and by year. Majors in Chemical, Bioengineering, Environmental, and Transport Systems (CBET) had higher scores on Overall Creativity than majors in Civil, Mechanical, and Manufacturing Innovation (CMMI), which in turn had higher scores than majors in Electrical, Communications, and Cyber Systems (ECCS). Students in their first year had significantly lower scores on overall creativity than students in their advanced years (second, third, or fourth year).

Divergent thinking measures (fluency, flexibility, and originality percentage) did not vary by major. However, first year students had significantly lower scores on fluency and flexibility than more advanced students (students in their second, third, or fourth year). There were no differences in originality percentage scores by year.

The results of multiple regression analyses for the four stages of creative problem solving indicated that none of the individual difference variables significantly predicted the quality of any of the four stages (problem recognition quality, idea generation quality, idea evaluation quality, and solution validation quality). The only individual difference variable to predict overall creativity was openness (only marginally). Knowledge, however, was a significant predictor of idea generation quality, solution validation quality, and overall creativity.

A multiple regression model showed that all four stages of creative problem solving (problem recognition quality, idea generation quality, idea evaluation quality, and solution validation quality) significantly predicted overall creativity. The quality of problem recognition and solution validation positively predicted overall creativity, whereas the quality of idea generation and idea evaluation negatively predicted overall creativity.

Creative problem solving stages were found to be associated with each other. Problem recognition quality significantly predicted idea generation quality as well as solution validation quality scores. Idea generation quality significantly predicted idea evaluation quality scores. However, idea evaluation quality was not predictive of solution validation quality.

The results of multiple regression analyses for the four academic outcomes indicated that none of the creative problem solving quality measures or the overall creativity were significantly associated with students' self-reported GPA, engineering GPA, or performance goals. Solution validation quality, however, was significantly associated with interest. Overall creativity was

significantly associated with learning goals, perceived ability, and interest. Overall creativity was not associated with engineering students' performance goals.

The findings of the path analysis model of creative problem solving stages and overall creativity reinforced the results of multiple linear regression explained earlier. That is, quality of problem recognition stage and solution validation stage positively predicted overall creativity, whereas the quality of idea generation and idea evaluation stages negatively predicted overall creativity. Total effects of these stages revealed that quality of solution validation had the strongest effect on overall creativity, followed by the effect of quality of problem recognition, the quality of idea evaluation, and finally the quality of idea generation.

Finally, the findings of the path analysis model of divergent thinking measures and overall creativity indicated that all three divergent thinking measures (fluency, flexibility, and originality percentage) significantly predicted overall creativity. The correlations between divergent thinking measures and the quality of idea generation were not significant. The only significant correlation among divergent thinking measures was the one between fluency and flexibility.

Discussion

Differences in Creative Problem Solving Stages and Overall Creativity

Results of the Analysis of Variance (ANOVA) on the four stages of creative problem solving as well as overall creativity were reflective of what is already known in the general creativity literature regarding the importance of problem recognition in the creative problem solving process (Reiter-Palmon, Mumford, & Threlfall, 1998; Reiter-Palmon & Robinson, 2009). Given the strength of the connection between the problem recognition stage and overall

creativity, it makes sense that this stage and overall creativity shared similar patterns in their relationships to variables such as year and major.

The results indicate that as engineering students advance in their college education they become more knowledgeable and thus better at the problem recognition stage and more creative at solving engineering-related problems. This finding likely reflects the importance of both expertise (Ericsson, 2014; Hunter, Cushenbery, & Friedrich, 2012) and domain-specific knowledge (Baer & Kaufman, 2005; J. C. Kaufman & Baer, 2004) in domain-specific creative work.

Major was also a significant factor indicating problem recognition scores as well as overall creativity scores varied by major. Particularly, CBET majors (Chemical, Bioengineering, Environmental, and Transport Systems) and CMMI majors (Civil, Mechanical, and Manufacturing Innovation) had higher scores on both Problem Recognition and Overall Creativity than ECCS majors (Electrical, Communications, and Cyber Systems); the CBET majors also showed higher overall creativity than the CMMI majors. It is possible that these differences are due to the specific nature of the engineering problem, which may have had less relevance to ECCS majors. However, it is also possible that such differences are genuine. It is worth noting that the CBET majors had significantly higher GPAs than the other two major groups; it is possible that if intelligence had been measured in this study there may have been differences as well.

There were also significantly more women among the CBET majors than the other two groups. Given the disparity in the engineering field and STEM programs in general, the female students who have persevered simply to the level of majoring in engineering have already faced numerous obstacles, such as stereotype threat (e.g., Gallagher & Kaufman, 2005). It is thus

possible that the females in this study may have higher levels of dedication, commitment, or ability. Such differences may have emerged if motivation had been measured in this study.

Differences in Divergent Thinking Measures

This study found no evidence that divergent thinking measures (fluency, flexibility, and originality percentage) vary by major. However, fluency and flexibility scores varied by year. Engineering students in advanced years (second, third, or fourth year in the program) had significantly higher fluency and flexibility scores than student in their first year of the engineering program. This finding suggests that as engineering undergraduates advance in their programs they acquire domain-specific knowledge that helps them in generating potential solutions of engineering-related problems as well as in giving multiple types of solutions. This finding is consistent with the patterns in problem recognition and overall creativity.

Individual Difference Variables and Creativity Measures

The second research question tackled the relationship between individual difference variables and creative measures (problem solving stages and overall creativity). Some of the findings were surprising. One unexpected finding was that openness to experience was not significantly associated with overall creativity. Openness to experience is traditionally found to be related to creativity (see review in J. C. Kaufman, 2009). Why did this study not reflect past results? The likely explanation is that due to time constraints personality traits were measured using the 10-item version of the Big Five Inventory scale (Rammstedt & John, 2007). Briefer measures of personality may not tap into the nuances of more in-depth measures, particularly for the Openness dimension (DeYoung, 2014). Further, when the openness construct is explored more thoroughly, it splits into openness and intellect. Openness (which is more experientially-related) is more associated with artistic creativity, whereas intellect is more associated with

scientific creativity (S. B. Kaufman et al., 2015). Openness as measured by the BFI is more experiential; thus, the way that openness was assessed in this study may be distinct from the aspect openness that is associated with scientific creativity.

Another surprising finding was that agreeableness predicted idea evaluation scores (i.e., people who are more agreeable were better at picking their own best ideas). Usually it is disagreeableness that is associated with creativity, particularly scientific creativity (Feist, 1998; Silvia, Kaufman, Reiter-Palmon, & Wigert, 2011). However, idea evaluation responses in this study were scored for quality, which may be closer to an intellectual or practical ability (i.e., choosing, selecting and picking the best idea). The more relevant literature may be studies on personality and general academic and organizational success, which generally show agreeableness as being associated with positive outcomes (Kyllonen et al., 2005; Mount, Barrick, & Stewart, 1998).

Domain-specific knowledge was predictive of idea generation, solution validation and overall creativity. These findings are consistent with how creativity and problem solving skills were also associated with year of study and likely again reflect the importance of domain-specific knowledge and expertise.

Overall Creativity and Creative Problem Solving Stages

This study also found relationships between the four stages of creative problem solving and overall creativity. Most notably (and as previously discussed), problem recognition was the stage most closely associated with creativity (Reiter-Palmon & Robinson, 2009).

Overall creativity was negatively related to both idea generation and idea evaluation. This finding initially seems counterintuitive, but there are many possible reasons. It is important to note that each stage was rated for quality, as opposed to creativity. The most original ideas are

not necessarily the best ideas. Something may be considered creative because of very strong originality and only marginal appropriateness; consider, too, that creators may be more likely to try to shock and offend when generating responses to an open-ended task (Burch, Pavelis, Hemsley, & Corr, 2005). The creativity raters may have given more credit to particularly original ideas, but the quality raters were likely more focused on relevance and feasibility. Often the best answers are the most obvious; they are practical and have been repeatedly shown to work. In this case, therefore, the high quality ideas that would be the best advice in real life may have contributed to lower scores for overall creativity.

Further, idea evaluation is a convergent task, requiring people to evaluate many different ideas. Convergent thinking is a key attribute in the big picture of creativity and innovation (A. Cropley, 2006). However, it is more focused on the appropriateness aspect of the definition of creativity than the originality aspect. Convergent thinking and divergent thinking often show no relationship (Claridge & McDonald, 2009). Even expert creativity raters will be more drawn to traditionally creative (and divergent) responses. People high on convergent thinking may thus receive lower creativity scores.

Solution validation positively predicted overall creativity. This finding is also likely related to connection between domain-specific knowledge and creativity, as has been discussed. The ability to discuss how to implement an idea is rooted in knowledge of that domain.

Creative Problem Solving Stages

Results of this study revealed positive associations among the stages of creative problem solving, which is consistent with most theoretical work (e.g., R. K. Sawyer, 2012). Specifically, problem recognition predicted idea generation, idea generation predicted idea evaluation, and problem recognition predicted solution validation. Idea evaluation did not predict solution

validation. It is possible that this finding is due to the specific nature of how this stage was implemented.

Creative Measures and Academic Outcomes

Findings of the study regarding the relationships between creative problem solving and overall creativity measures and academic outcomes revealed that the overall creativity was associated with learning goals, perceived ability, and interest in engineering. These findings are broadly consistent with the literature on creativity and intrinsic motivation (Amabile, 1996). People who are engaged in an activity for reasons of enjoyment and passion are more likely to be creative. Learning goals and interest in engineering are clearly linked to the concept of intrinsic motivation. Perceived ability is likely more connected to the idea of metacognition. People who are higher in ability also tend to be better at assessing their own ability (Dunning, Johnson, Ehrlinger, & Kruger, 2003), a concept that has been applied to creativity (J. C. Kaufman & Beghetto, 2013). People who are more creative or proficient at a task will likely view themselves as having high ability. Creativity was not related to GPA, which is generally consistent with studies that have found very small relationships between the two constructs (Grigorenko et al., 2009).

Path Analysis Model of Creative Problem Solving Stages and Overall Creativity

The findings of the path analysis model reinforced the role of quality of each stage of the problem solving skills in the creative process. Most notably (and as previously discussed in detail), the quality of problem recognition and solution validation were the strongest predictors of overall creativity. Both idea generation and idea evaluation were negatively related to overall creativity. These findings add to our understanding of the distinct roles that quality plays in the creative process. They further underscore the importance of the problem recognition stage; not

only does it directly predict creativity but it also indirectly influences creativity via its relationship to solution validation.

Path Analysis Model of Divergent Thinking Measures and Overall Creativity

The findings of this path model indicated that all divergent thinking measures (fluency, flexibility, and originality percentage) positively predicted overall creativity. Fluency had the strongest effect, followed by flexibility, and finally originality percentage. This finding might seem surprising since most people associate originality with creativity. However, recall that researchers recognize creativity as a combination of originality and usefulness (e.g., Plucker & Beghetto, 2004). Additionally, there are domain-based reasons why this pattern may be in effect here. Fluency is rooted in both creativity and intelligence; indeed, basic fluency assessments are part of some intelligence tests (see J. C. Kaufman, Kaufman, & Lichtenberger, 2011). Engineering creativity, like most aspects of scientific creativity, likely requires more intellectual skills than other domains of creativity (Park, Lubinski, & Benbow, 2007). Thus, the abilities reflected by the Fluency score may be most relevant for creativity in engineering.

The connection between fluency and flexibility is expected (they are often highly correlated). The low connection between originality and both fluency and flexibility might be because originality was calculated as a percentage score. When originality is measured by dividing the raw originality score by fluency (e.g., Plucker et al., 2014), it eliminates any bonus score that a high fluency participant may receive. A person with two very original ideas will earn higher originality percentage scores than someone with two very original ideas and five less-original ideas. One result is that originality is less likely to be highly correlated with fluency or flexibility.

Finally, the quality of idea generation was not particularly related to any of the divergent thinking measures. Consistent with other findings in this dissertation, this relationship reinforces that the highest quality ideas are not necessarily creative.

Implications

The findings of this study reinforced the importance of domain-specific knowledge and expertise for successful creative problem solving within that domain. It is thus vital for engineering programs that value creativity to (perhaps counterintuitively) ensure student acquisition of basic knowledge and content so that they can later apply such experience in a creative manner. However, another important finding of this study is the lack of connection between student GPA and creativity. This finding suggests that it is possible that creativity is not rewarded in the way that grades are given in engineering programs (which could be the case in schools in general). Given the growing call to foster creativity in education generally, and engineering education specifically (D. H. Cropley & Cropley, 2010; Kazerounian & Foley, 2007), engineering programs might need to both integrate creativity into their class assignments and reflect its importance in the grading system.

The results of this research have also highlighted the significant role of problem recognition in the creative problem solving progression. It is therefore important for engineering education to enhance these abilities in engineering students. It is the engineering professors' responsibility to create opportunities (through exercises, assignments, and activities) for their students to allow them to develop and reinforce this skill.

This study has also found that creativity was significantly related to students' learning goals, perceived ability, and interest in engineering. Thus, if an engineering program seeks creative students, they should focus on the skills that will best help creative performance within

the engineering domain (Csikszentmihalyi, 1999), in this case people who want to learn and have a strong interest. It is worth noting that these skills are likely already desired qualities; nevertheless, this study reinforces their importance.

Limitations

Like the majority (if not all) of research, this study had several limitations associated with it. One limitation was that the sample in this study consisted of engineering students, not professional engineers. There are many differences between students and professionals; indeed, not all students will become professionals. Ideally, it would be possible to follow up on these students in several years to see which ones had become successful engineers.

In addition, there is a certain variation in commitment to engineering and knowledge of engineering that could not be controlled for. For example, some freshman students might have extensive experience in engineering (for example, from a summer job) and some seniors may have only some class experience. Similarly, although the problem was written in consultation with engineering professors, it still required some specific background knowledge. Although there was a measure of engineering knowledge included, this variable could not encompass the many ways that past experiences and background knowledge varied among participants.

A further limitation in this study reflects a limitation in the engineering field, which is that the number of men in the sample was larger than the number of women (377 males and 124 females). Similarly, freshman students in this study were overrepresented.

Finally, this study is limited in its generalizability. The sample was a convenience sample, and not a randomized or stratified sample. That is, because of the nature of conducting research with university students, all participants are attending undergraduate engineering programs at a single northeastern university. There is a certain amount of restriction of range

given that all participants have a comparable level of education. Further, the demographics of the study do not reflect those of the national population or of the field of engineering. As a result, it is not possible to completely extend findings from this study to other engineering programs in other universities where student-body diversity might be different.

In addition, this specific university engineering school has a notable interest in creativity (with several prominent members of the department either demonstrating an interest or even publishing on the topic), which is likely not true for other engineering schools. Thus, this engineering program may have created a pro-creative atmosphere, whereas programs with less interest in creativity may show a different pattern or lower results.

Future Directions

This study was designed to investigate creative problem solving stages across multiple engineering domains and the general-engineering problem that was created for the purpose of this study required only written responses. As a result, the prompt was particularly dependent on verbal abilities. One possible future study could be to ask people to design or actually build a structure or object where the outcome variable would be a product that would be evaluated for quality and creativity criteria (D. H. Cropley & Kaufman, 2012). That way creativity would be measured in a more objective way.

Also, results regarding personality traits suggest the significance of further exploration to explore if the profile of a creative engineer is different from the profile of a creative person in general (or in other sciences). Given the importance of function to engineering creativity (D. H. Cropley, 2015; D. H. Cropley & Cropley, 2005), it is possible that there are different personality traits associated with the creative process than with other domains.

Another possible future direction is to study engineering education at a younger age. Engineering education begins before college (Katehi et al., 2009), and thus, in order to inform engineering education there is a need for similar type of research in high school or even earlier. Such studies could investigate how students might solve comparable engineering-related problems in eighth grade compared to in twelfth grade.

Finally, and potentially most fascinating, further investigations and follow-up to this study would be to see which ones of these participants end up in professional engineering jobs and which ones don't; or which ones are successful and which ones are not. A potential future study might be to look at the developmental trajectory of creativity in a typical engineer by assessing performance on several different types of problems in both early-career and later-career professionals. These types of questions, among others, could be studied through a longitudinal design that could be conducted to also assess changes in the creative process and overall performance over time. Such results could contribute to creativity development in engineering education at different levels and better attract young students to engineering programs and further equip them to be creative engineers.

Conclusion

In-depth investigations of the creative problem solving processes in postsecondary engineering education have yet to be done. This study was one of the first to explore the full range of the creative process in undergraduate engineering students. I believe that this research can provide a launching pad for future work on engineering students' creative thinking skills, the potential relationship between individual differences measures and engineering creativity, and the possible association between different aspects of creativity and specific desired educational outcomes. The core results emphasize the importance of problem recognition, domain

knowledge, and experience to the creative process. These findings, along with other past research, can be used to help advise engineering education for how to best nurture student creativity.

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Appendices

Appendix A: Demographic Information Form

Please enter the information below.

Gender: ___ M ___ F ___ Prefer not to say

Age: _________

Engineering Major: ___________________

Year you are in the program at this point:

____Freshman ____ Sophomore ____ Junior ____Senior ____Graduate

Overall GPA at UConn (best estimate): _________

Average GPA in Engineering Classes (best estimate): _________

Last Semester GPA (best estimate): _________

Appendix B: Engineering-Related Problem

Please read the following scenario carefully and wait until you are asked to respond to each of the following questions. Please feel free to be creative!

"I recently moved into an old farm house and I was horrified when I received the bills for the first quarter. The electricity bill was twice what I am used to; I had to pay triple what I was paying in my last place for oil. What can I do?"

- Identify an engineering-related problem that you find in this scenario and explain it in detail in one or two sentences.

- Think of potential solutions to this problem. List as many different ideas as you can that might solve it.

- Out of all of your potential solutions, which idea would you select as your best idea that you would choose to implement to solve the problem?

- Finally, think of how you would validate and carry out your solution. In two or three sentences, explain what your plans for implementation.

Appendix C: Knowledge Measure

Please write a number next to each statement to indicate the extent to which you are familiar with the topic.

Not familiar at all 1	Not familiar 2	Slightly familiar 3	Somewhat familiar 4	Familiar 5	Very familiar 6

- _____ The topic of energy
- _____ Engineering problem solving.
- _____ Recent innovations in energy.
- _____ Household energy saving

Appendix D: Personality Measure

Big Five Inventory-10 (BFI-10; Rammstedt & John, 2007)

Here are a number of personality traits that may or may not apply to you. Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

Strongly Disagree 1	Disagree 2	Somewhat Disagree 3	Somewhat Agree 4	Agree 5	Strongly Agree 6

I see myself as someone who:

1. _____ is reserved
2. _____ is generally trusting
3. _____ tends to be lazy
4. _____ is relaxed, handles stress well
5. _____ has few artistic interests
6. _____ is outgoing, sociable
7. _____ tends to find fault with others
8. _____ does a thorough job
9. _____ gets nervous easily
10. ____ has an active imagination

Appendix E: Creative Self-Efficacy in Engineering Measure

(Adapted from Beghetto, 2006, 2009)

Please write a number next to each statement to indicate the extent to which you see that each statement is true about you.

Not at all true of me 1	Not true of me 2	Slightly true of me 3	Some what true of me 4	True of me 5	Very true of me 6

- _____ I am good at coming up with new ideas for solving engineering problems.
- _____ I have a lot of good ideas about how to solve engineering problems.
- _____ I have a good imagination when it comes to engineering problems.
- _____ I am confident that I can produce multiple solutions to engineering problem.
- _____ I am confident that I can produce useful solutions to engineering problems.
- _____ I am confident that I can solve non-routine engineering problems.

Appendix F: Learning Goals, Performance Goals, and Perceived Ability In Engineering

(Adapted from Elliot & McGregor, 2001)

Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

Strongly Disagree 1	Disagree 2	Somewhat Disagree 3	Somewhat Agree 4	Agree 5	Strongly Agree 6

Learning Goals
I do the engineering work assigned because:

1. _____ … I like to understand really complicated ideas.
2. _____ … I like to work hard to solve challenging problems.
3. _____ … I like learning interesting things.
4. _____ … I like to understand the material I study.

Performance Goals
I do the engineering work assigned because:

1. _____ … I want look smart to my friends.
2. _____ … I don't want others to think I'm not smart.
3. _____ … I can show people that I am smart.
4. _____ … I like to do better than other students.
5. _____ … I don't want to be the only one who cannot do the work well.
6. _____ … I don't want to look foolish or stupid to my friends, family, or teachers.
7. _____ … I like to score higher than other students.
8. _____ … I don't want to be embarrassed about not being able to do the work.

Perceived Ability
1. _____ I have a good understanding of the engineering concepts I've been taught.
2. _____ I am confident I have the ability to understand the ideas taught in engineering courses.
3. _____ I am certain I understand engineering problem solving skills.
4. _____ I am confident about my ability to do well in engineering courses.
5. _____ Compared with other students in this major my skills are weak.
6. _____ I think I am doing better than other students in this major.
7. _____ Relative to others in this major, I think I am good at engineering-related skills.
8. _____ I am confident I can perform as well or better than others in this major.

Appendix G: Academic Interest In Engineering

(Adapted from Harackiewicz et al., 2000)

Please write a number next to each statement to indicate the extent to which you agree or disagree with that statement.

Strongly Disagree 1	Disagree 2	Somewhat Disagree 3	Somewhat Agree 4	Agree 5	Strongly Agree 6

1. _____ I think the field of engineering is very interesting.
2. _____ I think my engineering major is very interesting.
3. _____ I think I will be able to use what I learn in my engineering major in my career.
4. _____ I would recommend this engineering major to others.
5. _____ I am enjoying taking classes in the engineering major.
6. _____ My engineering major is not the best fit for my career interests.
7. _____ I'm glad I specifically chose this engineering major.
8. _____ I think the course materials that I am taking in my engineering classes are useful for me to learn.
9. _____ I would like to take more engineering classes after this one.
10. ____ I am more likely to go for a graduate degree in engineering because of my experience in the engineering major.

Appendix H: Drawing Info Sheet

Please enter the information below if you would like to be entered into a drawing for one of four $25 Amazon gift cards. At no point will your personal information be associated with your responses.

Name: ____

Preferred e-mail: ________________________________

PeopleSoft ID: ____________________________________

Appendix I: Raters Instructions

Problem Recognition Scoring Instructions

Undergraduate engineering students were asked to write responses to the following general open-ended engineering problem.

Please read the following scenario carefully and answer each of the following questions. Please feel free to be creative!
"I recently moved into an old farm house and I was horrified when I received the bills for the first quarter. The electricity bill was twice what I am used to; I had to pay triple what I was paying in my last place for oil. What can I do?"

1. Identify an engineering-related problem that you find in this scenario and explain it in detail in one or two sentences.
2. Think of potential solutions to this problem. List as many different ideas as you can that might solve it.
3. Out of all of your potential solutions, which idea would you select as your best idea that you would choose to implement to solve the problem?
4. Finally, think of how you would validate and carry out your solution. In two or three sentences, explain what your plans for implementation.

Raters:
Please note that you will be scoring the responses to Question #1. It is the one given to you in this excel file (sheet 1). Please rate the responses to the question that is given to you using a six-point Likert scale (1 = lowest quality, 6 = highest quality).
You will be rating the overall quality of the participants' responses based on your own definition of what entails a high-quality response. Try to use the full range of the scale as much as possible (for example, try to not give just 1s and 2s or just 5s and 6s).
You can change your ratings as much as you wish, but there is no need to spend a large amount of time on this -- just give your best expert judgment of the quality of each response.

Thank you!!

Idea Generation Scoring Instructions

For this project, undergraduate engineering students responded to the following multi-part, open-ended engineering problem, as directly reproduced below:

Please read the following scenario carefully and answer each of the following questions. Please feel free to be creative!
"I recently moved into an old farm house and I was horrified when I received the bills for the first quarter. The electricity bill was twice what I am used to; I had to pay triple what I was paying in my last place for oil. What can I do?"

1. Identify an engineering-related problem that you find in this scenario and explain it in detail in one or two sentences.
2. Think of potential solutions to this problem. List as many different ideas as you can that might solve it.
3. Out of all of your potential solutions, which idea would you select as your best idea that you would choose to implement to solve the problem?
4. Finally, think of how you would validate and carry out your solution. In two or three sentences, explain what your plans for implementation.

Instructions for Raters:

Please note that you will only be scoring the responses to Question #2. These responses are located in this same excel file (sheet 1). Please rate *each specific idea* using a six-point scale. A score of "1" represents the lowest quality, and a score of "6" represents the highest quality. You will be rating the quality of the participants' ideas based on your own definition of what entails a high-quality response. Try to use the full range of the scale as much as possible (for example, try to not give just 1s and 2s or just 5s and 6s).

You can change your ratings as much as you wish, but there is no need to spend a large amount of time on this -- just give your best expert judgment of the quality of each response. You may wish to read a certain number of ideas to get a feeling for the responses. Please give your rating by comparing the ideas to each other, as opposed to an ideal answer.

Please note that the red color indicates a new participant's response.

Ideas were sometimes separated when multiple ideas were listed in one thought, so that the wording of the some ideas may sound repetitive. This was done because the quality of ideas may vary even when initially given in a list form. For example, imagine if you were asked how to feed yourself. If a person wrote "Someone might buy paper bags and apples at the grocery store," it would be reformatted so that one idea read "Someone might buy paper bags at the grocery store" and "Someone might buy apples at the grocery store." Even though they were listed together, one idea (apples) is of higher quality than the other (paper bags). For this reason, some of the responses from a participant may sound repetitive; please do not let this negatively influence your ratings of the idea's quality.

Thank you!!

Solution Validation Scoring Instructions

Undergraduate engineering students were asked to write responses to the following general open-ended engineering problem.

Please read the following scenario carefully and answer each of the following questions. Please feel free to be creative!

"I recently moved into an old farm house and I was horrified when I received the bills for the first quarter. The electricity bill was twice what I am used to; I had to pay triple what I was paying in my last place for oil. What can I do?"

1. Identify an engineering-related problem that you find in this scenario and explain it in detail in one or two sentences.
2. Think of potential solutions to this problem. List as many different ideas as you can that might solve it.
3. Out of all of your potential solutions, which idea would you select as your best idea that you would choose to implement to solve the problem?
4. Finally, think of how you would validate and carry out your solution. In two or three sentences, explain what your plans for implementation.

Raters:

Please note that you will be scoring the responses to Question #4. It is the one given to you in this excel file (sheet 1). Please rate the responses to the question that is given to you using a six-point Likert scale (1 = lowest quality, 6 = highest quality).

You will be rating the overall quality of the participants' responses based on your own definition of what entails a high-quality response. Try to use the full range of the scale as much as possible (for example, try to not give just 1s and 2s or just 5s and 6s).

You can change your ratings as much as you wish, but there is no need to spend a large amount of time on this -- just give your best expert judgment of the quality of each response.

Thank you!!

Overall Creativity Scoring Instructions

Undergraduate engineering students were asked to write responses to the following general open-ended engineering problem.

Please read the following scenario carefully and answer each of the following questions. Please feel free to be creative!

"I recently moved into an old farm house and I was horrified when I received the bills for the first quarter. The electricity bill was twice what I am used to; I had to pay triple what I was paying in my last place for oil. What can I do?"

1. Identify an engineering-related problem that you find in this scenario and explain it in detail in one or two sentences.
2. Think of potential solutions to this problem. List as many different ideas as you can that might solve it.
3. Out of all of your potential solutions, which idea would you select as your best idea that you would choose to implement to solve the problem?
4. Finally, think of how you would validate and carry out your solution. In two or three sentences, explain what your plans for implementation.

Raters:

Please note that you will be scoring the responses to the OVERALL CREATIVITY of the responses to all 4 questions. Please rate the responses using a six-point Likert scale (1 = least creative, 6 = most creative) to assess the holistic creativity of each participant's responses to all four questions.

You will be rating the overall creativity of the participants' responses based on your own definition of what entails a creative response. Try to use the full range of the scale as much as possible (for example, try to not give just 1s and 2s or just 5s and 6s).

You can change your ratings as much as you wish, but there is no need to spend a large amount of time on this -- just give your best expert judgment of the creativity of each overall response of a participant.

Thank you!!

Appendix J: Tables

Table J.1. *Gender Frequency*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**Male**	377	74.7	75.2	75.2
	Female	124	24.6	24.8	100.0
Total		501	99.2	100.0	
Missing		4	.8		
Total		505	100.0		

Table J.2. *Major Frequency*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**CBET**	179	35.4	35.4	35.4
	CMMI	147	29.1	29.1	64.6
	ECCS	136	26.9	26.9	91.5
	Other	43	8.5	8.5	100.0
Total		505	100.0	100.0	

Note. CBET: Chemical, Bioengineering, Environmental, & Transport Systems; CMMI: Civil, Mechanical, & Manufacturing Innovation; ECCS: Electrical, Communications, & Cyber Systems.

Table J.3. *Year Frequency*

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	**First**	371	73.5	73.5	73.5
	Advanced	134	26.5	26.5	100.0
Total		505	100.0	100.0	

Table J.4. *Differences in Overall GPA by Major*

Major		**Mean Difference**	**Std. Error**	**Sig**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
CBET	**CMMI**	.204*	.051	.000	.104	.303
	ECCS	.170*	.054	.002	.065	.275
CMMI	**CBET**	-.204*	.051	.000	-.303	-.104
	ECCS	-.034	.055	.543	-.143	.075
ECCS	**CBET**	-.170*	.054	.002	-.275	-.065
	CMMI	.034	.055	.543	-.075	.143

Note. * = The mean difference is significant at the 0.05 level.

Table J.5. *Differences in Engineering GPA by Major*

Major		**Mean Difference**	**Std. Error**	**Sig**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
CBET	**CMMI**	.154*	.061	.011	.035	.273
	ECCS	.191*	.064	.003	.066	.317
CMMI	**CBET**	-.154*	.061	.011	-.273	-.035
	ECCS	-.037	.066	.572	-.093	.167
ECCS	**CBET**	-.191*	.064	.003	-.317	-.066
	CMMI	-.037	.066	.572	-.167	.093

Note. * = The mean difference is significant at the 0.05 level.

Table J.6. *Differences in Knowledge by Major*

Major		**Mean Difference**	**Std. Error**	**Sig**	**95% Confidence Interval**	
					Lower Bound	**Upper Bound**
CBET	**CMMI**	-.137	.129	.287	-.391	.116
	ECCS	.101	.136	.458	-.166	.368
CMMI	**CBET**	.137	.129	.287	-.116	.391
	ECCS	.238	.141	.091	-.038	.515
ECCS	**CBET**	-.101	.136	.458	-.368	.166
	CMMI	-.238	.141	.091	-.515	.038

Note. * = The mean difference is significant at the 0.05 level.

Table J.7. *Differences in Creative Self-Efficacy by Major*

Major		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
CBET	**CMMI**	-.046	.108	.672	-.258	.166
	ECCS	.084	.114	.462	-.140	.308
CMMI	**CBET**	.046	.108	.672	-.166	.258
	ECCS	.130	.118	.272	-.102	.361
ECCS	**CBET**	-.084	.114	.462	-.308	.140
	CMMI	-.130	.118	.272	-.361	.102

Note. * = The mean difference is significant at the 0.05 level.

Table J.8. *Differences in Learning Goals by Major*

Major		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
CBET	**CMMI**	.024	.084	.771	-.140	.189
	ECCS	.041	.088	.642	-.132	.214
CMMI	**CBET**	-.024	.084	.771	-.189	.140
	ECCS	.017	.091	.856	-.163	.196
ECCS	**CBET**	-.041	.088	.642	-.214	.132
	CMMI	-.017	.091	.856	-.196	.163

Note. * = The mean difference is significant at the 0.05 level.

Table J.9. *Differences in Performance Goals by Major*

Major		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
CBET	**CMMI**	.078	.133	.558	-.184	.340
	ECCS	.241	.140	.086	-.034	.516
CMMI	**CBET**	-.078	.133	.558	-.340	.184
	ECCS	.163	.145	.264	-.123	.448
ECCS	**CBET**	-.241	.140	.086	-.516	.034
	CMMI	-.163	.145	.264	-.448	.123

Note. * = The mean difference is significant at the 0.05 level.

Table J.10. *Differences in Perceived Ability by Major*

Major		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
CBET	**CMMI**	-.031	.090	.728	-.208	.145
195	**ECCS**	.009	.095	.927	-.178	.195
CMMI	**CBET**	.031	.090	.728	-.145	.208
	ECCS	.040	.098	.684	-.153	.233
ECCS	**CBET**	-.009	.095	.927	-.195	.178
	CMMI	-.040	.098	.684	-.233	.153

Note. * = The mean difference is significant at the 0.05 level.

Table J.11. *Differences in Interest by Major*

Major		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
CBET	**CMMI**	-.137	.095	.150	-.324	.050
	ECCS	.006	.100	.952	-.190	.202
CMMI	**CBET**	.137	.095	.150	-.050	.324
	ECCS	.143	.104	.168	-.061	.347
ECCS	**CBET**	-.006	.100	.952	-.202	.190
	CMMI	-.143	.104	.168	-.347	.061

Note. * = The mean difference is significant at the 0.05 level.

Table J.12. *Differences in Overall GPA by Year*

Year		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
First	**Advanced**	.025	.044	.572	-.061	.110
Advanced	**First**	-.025	.044	.572	-.110	.061

Note. * = The mean difference is significant at the 0.05 level.

Table J.13. *Differences in Engineering GPA by Year*

Year		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
First	**Advanced**	.095	.052	.069	-.007	.197
Advanced	**First**	-.095	.052	.069	-.197	.007

Note. * = The mean difference is significant at the 0.05 level.

Table J.14. *Differences in Knowledge by Year*

Year		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
First	**Advanced**	-.435*	.110	.000	-.652	-.218
Advanced	**First**	.435*	.110	.000	.218	.652

Note. * = The mean difference is significant at the 0.05 level.

Table J.15. *Differences Creative Self-Efficacy by Year*

Year		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
First	**Advanced**	-.140	.092	.130	-.322	.041
Advanced	**First**	.140	.092	.130	-.041	.322

Note. * = The mean difference is significant at the 0.05 level.

Table J.16. *Differences in Learning Goals by Year*

Year		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
First	**Advanced**	-.114	.072	.113	-.254	.027
Advanced	**First**	.114	.072	.113	-.027	.254

Note. * = The mean difference is significant at the 0.05 level.

Table J.17. *Differences in Performance Goals by Year*

Year		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
First	**Advanced**	-.094	.114	.410	-.318	.130
Advanced	**First**	.094	.114	.410	-.130	.318

Note. * = The mean difference is significant at the 0.05 level.

Table J.18. *Differences in Perceived Ability by Year*

Year		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
First	**Advanced**	-.226*	.077	.003	-.378	-.075
Advanced	**First**	.226*	.077	.003	.075	.378

Note. * = The mean difference is significant at the 0.05 level.

Table J.19. *Differences in Interest by Year*

Year		Mean Difference	Std. Error	Sig	95% Confidence Interval	
					Lower Bound	**Upper Bound**
First	**Advanced**	-.007	.081	.933	-.167	.153
Advanced	**First**	.007	.081	.933	-.153	.167

Note. * = The mean difference is significant at the 0.05 level.