DISSERTATION

EXPLORING THE RELATIONSHIPS AMONG CREATIVITY, ENGINEERING KNOWLEDGE, AND DESIGN TEAM INTERACTION ON SENIOR ENGINEERING DESIGN PROJECTS

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ABSTRACT

EXPLORING THE RELATIONSHIPS AMONG CREATIVITY, ENGINEERING KNOWLEDGE, AND DESIGN TEAM INTERACTION ON SENIOR ENGINEERING DESIGN PROJECTS

In the 21st century, engineers are expected to be creative and work collaboratively in teams to solve or design new products. Research in the past has shown how creativity and good team communication, together with knowledge, can impact the outcomes in the organization. The purpose of this study was to explore the relationships among creativity, engineering knowledge, and team interaction on senior engineering design product outcomes. The study was conducted within the College of Engineering, Department of Mechanical Engineering, at Colorado State University. A purposeful sampling of 55 students who enrolled in Mechanical Engineering Design capstone course completed the instruments during this study, which included the Torrance Tests of Creative Thinking (TTCT) Figural Form A, and a pre and post Team Climate Inventory. Students were assigned to twelve design project teams at the beginning of the fall term, 2011, and the project outcomes were evaluated in the spring of 2012, during the senior design showcase. Eleven professional engineers and three graduate students were trained to evaluate the senior design outcomes. The students' engineering grade point average (GPA) was used as a proxy to represent engineering knowledge.

Descriptive statistics were utilized to describe the sample in terms of their engineering GPA, creativity score, and team interaction score. Correlational analyses were executed to examine the relationships among the constructs of the study. At the design team level, results from this research indicate that there was no statistical significant relationship between the teams’ creativity composite score and the design outcome. There was also no statistical significant relationship between the team interaction score and the design outcome. The team composite creativity score had no significant relationship with the team interaction score. The composite of team engineering knowledge had no significant relationship to the team interaction score. At the individual level, the correlation analysis indicated there was no statistically significant relationship between student engineering knowledge and the creativity score.

Exploratory data analysis (EDA) was used to assess the interaction of the main constructs on the engineering design outcome. The EDA results indicate that only one team met the hypothesis that a team scored above average on engineering knowledge and creativity, and a positive team interaction climate would expect to score above average on their design outcome score. Two design teams scored above average on creativity and engineering knowledge, and positive team interaction climate yet scored below average on their design outcome, which went against the original hypothesis. One design team scored above average on their design outcome, but scored below average on the other three main constructs of the study. The remaining eight design teams did not show any consistent pattern of relationships among the three constructs and the design outcome score.

This research adds to the body of work within creativity, engineering knowledge, and team interaction climate in engineering design, as well as engineering education. The findings suggest that creativity, engineering knowledge, and team interaction climate had little impact on the engineering design outcomes. The limitations and implications of the study and future research are also discussed.

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DEDICATION

To my parents Ibrahim Muhamad and Madzidah Abdul Hamid, my lovely wife Norlida Shaari and our lovely three kids Fatin Nabilah Badaruddin, Asyraf Danial Badaruddin, and Adam Zharfan Badaruddin, I could not have made it through without you all.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

"I think if engineers are not creative, they're not engineers" – Elliott (2001)

History has shown that people have always relied on science and technology to find solutions to their daily problems and improve the quality of their lives. For example, the development of farming approaches/methods has evolved from the earliest methods of farming with human labor and using animals that only could feed a small population, to the use of advanced and sophisticated machines that could supply entire nations and feed the world's population. As the world becomes more economically competitive, each nation must continuously strive to maintain their advantages and leadership in technological inventions and integrative processes (Reader, 2006).

Industrialization is very closely related to the growth and development of science and technology. New discoveries and inventions continually challenge the industrialization process. No one can doubt the role of engineers in fueling the great revolution in science and technology (Alger & Hays, 1964). However, global market demands have forced engineers to develop goods and products at a faster pace and per lower cost (Frankenberger & Auer, 1997; Hicks, Culley, Allen, & Mullineux, 2002). To date, engineers continue to drive industries by creating solutions to secure competitive advantages (Reader, 2006).

In practice, engineers do not work alone in solving engineering problems. History shows that innovation does not come from one person. For example, the Wright brothers were working together with Charlie Taylor as a team to accomplish their mission to build a flying machine. The research and development (R&D) department or groups may have numbers of engineers or management teams collaborating among each other to realize the company or corporation goals. Therefore, engineers need to be trained to work and communicate in teams.

Bachelor’s degree level engineering education has been designed to produce excellent engineers who will do high quality work that will help corporations and nations to excel (Moritz, 1998). Moritz (1998) defined excellent engineers as those who meet the characteristics of being inspirational, excellent technical problem solvers, able to produce devices or systems, and are creative. Moritz (1998) also argued that excellent engineers should not only benefit their employers and the nation, but also must benefit the global community.

Statement of Problem

The world of industry must change in order to remain competitive in the 21st century. With the rapid development of information technology, industries need to respond quickly to new opportunities with creative and innovative products (Kemper & Sanders, 2001). Most industries would expect their hired engineers to be creative and help them to sustain their competitiveness in the global market (Kemper & Sanders, 2001).

There is no doubt that engineers must have sufficient domain-specific knowledge to be applied in their daily work that could be considered their own individual database of information (Rugarcia, Felder, Woods, & Stice, 2000). However, in the 21st century, engineers are also required to have other skills such as teamwork and communication skills. It has been reported that teamwork and communication skills among new engineering graduates are some of the most desirable skills needed by the industry

(Felder, Woods, Stice, & Rugarcia, 2000; Rugarcia, et al., 2000). Although teamwork and communication were recognized as the most important skills needed by industry, Kemper and Sanders (2001) reported that most of the engineering schools failed to prepare their engineering graduates for working in a team environment.

Creativity has long been recognized as important in engineering design. Creativity in engineering design is often found as an area of emphasis in engineering textbooks. For example, Cross (2008) in his textbook stated, “When designers are asked to discuss their abilities and to explain how they work, a few common themes emerge. One theme is the importance of creativity and ‘intuition’ in design – even in engineering design” (p. 19). In addition, Haik (2003) stated “In the systematic design process, creativity is utilized in all steps” (p. 119). Despite the fact that creativity is an important element in the engineering profession, engineering educators still face difficulties in assessing or quantifying creativity among their students. One reason could potentially come from the abstract nature of creativity itself and even now, there is no single definition of creativity that has been agreed upon among scholars.

There are a number of studies that have looked at creativity in students. It has been reported that the creativity levels among American students decreased from 1990 to 2008 (Shellenbarger, 2010). Furthermore, Simonton (1983) found a curvilinear inverted “U” shaped relationship between formal education and creativity, in which low and high education levels were correlated with low creativity, but medium education levels were correlated with high creativity. Surprisingly, the decline in creativity starts around the third year of college. However, there are few studies related to creativity among engineering students in college.

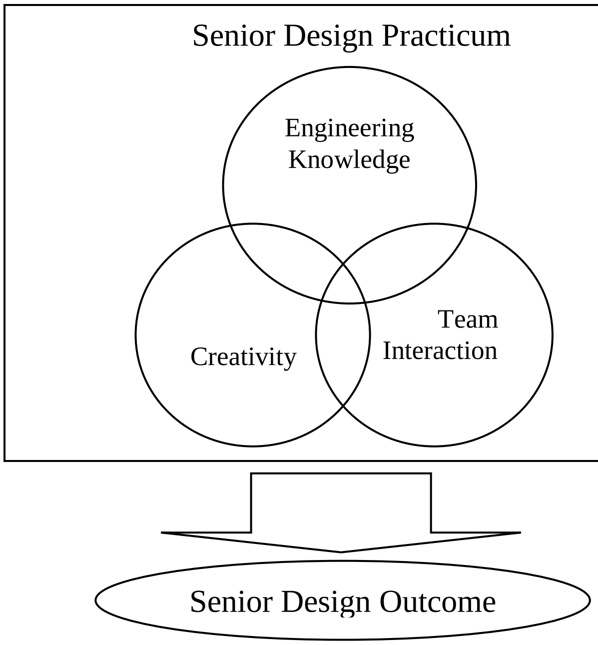


Figure 1.1. Theoretical relationships among creativity, engineering knowledge, and team interaction on design outcome in senior design practicum

The problem this research study seeks to address is to understand the relationships among creativity, engineering knowledge, and team interaction constructs and how these three variables interact with each other and impact engineering design outcomes. This represents the problem space of the study and it is unknown if these variables interact. Due to the complex problem of the study with multiple facets, Figure 1.1 helps to illustrate the theoretical relationships among the constructs. A study assessing the interaction among creativity, engineering knowledge, and teamwork among college-level engineering students is necessary to ensure not only the quality of students who are graduating, but also the future quality of life of all people who depend on engineers.

Statement of Purpose

The purpose of this study is to explore the relationships among creativity, engineering knowledge, and design team interaction on creative products or solutions in engineering design. The importance of this investigation focused on the challenges facing complex engineering organizations that require the efforts of creative teams to develop solutions to be used to replicate, sustain, and compete in the global market (Jassawalla & Sashittal, 1998). In higher education, students gain particular sets of engineering knowledge that are prescribed. However, could faculty choose better instructional strategies for students to learn teamwork and creativity? We do know that professional engineers work in teams but are there appropriate assessments for collaborative work at the college level? The aim of the study, therefore, is to gain insight into the relationships among creativity, engineering knowledge, and team interaction on creative products or solutions in engineering design.

Significance of the Study

According to Lumsdaine, Lumsdaine, and Shelnutt (1999), since the Accreditation Board for Engineering and Technology (ABET) has recognized the value of developing effective multidisciplinary teamwork skills among engineering graduates, it has become important for engineering schools to demonstrate their students' ability to work in teams. To address this, schools have implemented team projects as a required component of their engineering education. To meet a project's main goal, the designers (students) have to work productively as a team. Studies have shown there are significant relationships between creativity and team interaction in producing a creative product as a team (Cross & Cross, 1995; Thatcher & Brown, 2010).

Thompson and Lordan (1999) argued “engineering designers are expected to be creative” (p. 29) and this is currently becoming a core mission statement of engineering education in the United States (Charyton & Merrill, 2009; Middleton, 2005). In the United States, 81% of employers agree that creativity is important for future workforce entrants (Casner-Lotto & Barrington, 2006, p. 10). On the other hand, many engineering education courses do not have in-depth work that requires creativity, and many institutions are not using practical methods to assess creativity (Charyton & Merrill, 2009; Thompson & Lordan, 1999). Assuming creativity is a component in successful engineering design, it is important to be able to measure/assess creativity to assure added value in engineering education. Measuring creativity “is necessary to acknowledge that acts of creativity can and do occur in any workplace environment” (Thatcher & Brown, 2010, p. 291) and creative thinking can be developed and fostered effectively by educators (Sawyer, 2006) helping educate more successful engineers.

Competitiveness, innovation, and creativity in engineering education have driven this study. All three factors (creativity, engineering knowledge, and team interaction) combine significantly toward the real focus of this study, producing creative outcomes or solutions in engineering design. Research has shown that these three factors have significant implication on product outcomes such as competitiveness, cost, invention, and global market. We must expand our understanding across other factors (i.e., creativity and team interaction) in addition to engineering knowledge, to improve engineering education. In order to produce brilliant, excellent, and innovative products, engineers must possess multiple skills and capabilities.

This study seeks to explore the facets of creativity and teamwork among engineering students in college as outcomes in engineering design. By understanding creativity and the environment of teamwork among students and how it interacts with their current engineering knowledge, instructors and students will be assured of a competitive advantage. Moreover, this research will provide recommendations on how to assess creativity, team interaction, and design outcome in engineering design projects.

Research Questions

This study examined the impact that the three variables of student creativity level, engineering knowledge, and design team interaction had on the outcomes of an engineering design project in a senior level engineering design capstone course. The research questions examined in this study include:

1. What is the relationship between team composite creativity score and senior design outcome?
2. What is the relationship between team interaction score and senior design outcome?
3. What is the relationship between team composite creativity score and team interaction score?
4. What is the relationship between composite engineering course GPA and creativity score?
    a. What is the relationship between mathematics courses GPA and creativity score?

   b. What is the relationship between physics courses GPA and creativity score?
   c. What is the relationship between chemistry courses GPA and creativity score?
   d. What is the relationship between engineering sciences courses GPA and creativity score?
   e. What is the relationship between engineering design courses GPA and creativity score
5. What is the relationship between composite engineering knowledge GPA and team interaction score?
6. What is the interaction between creativity, engineering knowledge, and team interaction on senior design outcome?

Therefore the direction of this study in terms of the research questions, relates to creativity, engineering knowledge, and team interaction on engineering design outcome.

Conceptual Framework

There are three main constructs in this study: (1) Engineering knowledge, (2) Creativity, and (3) Team interaction. This research examined the impact of these three constructs on the outcome of a senior design project. Figure 1.1 helps illustrates the relationships among creativity, engineering design knowledge, and team interaction on senior design outcome.

Engineering Knowledge

Engineering is a profession that requires knowledge of mathematics and natural sciences gained through learning, experience, and practice (Eide, Jenison, Mashaw, & Northup, 2002). This knowledge is then applied to product development or solutions especially in engineering design. Besides having engineering knowledge (e.g., to determine the strength of materials and how to select the right materials), knowledge of the process of engineering design is essential in solving a design problem. According to Eder and Hosnedl (2008), engineering design involves four main phases: (1) elaborating the assigned problem, (2) conceptualizing the design, (3) laying out the design, and finally (4) detailing the design. Each phase involves special tasks or strategies to meet the goal of the project. Engineering Design Process (EDP) phases can be described from the main steps to the most specific and detailed process. The design methods “represent a number of distinct kinds of activities that the designer might use and combine into a overall design process” (Cross, 2008, p. 46). According to Hill (1998), “regardless of the degree of complexity, all models describe a common thread: a process that moves from the inception of an idea to the reflection stage in order to verify if the developed model, prototype or system functions as intended” (p. 204).

Creativity

Drabkin (1996) defines creativity in engineering as “the ability of human intelligence to produce original ideas and solutions using imagination” (p. 78). It is different from other fields, as Cropley and Cropley (2005) stated, “engineering creativity is different from other fields like fine arts and it is clearly seen through the product, device, or system being developed by the engineers that perform the task or solve problems" (p. 171). Furthermore, "creativity is usually apparent in all stages of design processes, but is particularly prominent in the early stages" (A. M. Hill, 1998, p. 204). Others scholars in engineering design have the same view as Hill (1998) and admit that creativity is essential in engineering design (e.g., Cross, 2008; Haik, 2003; Vzyatishev,1991).

Teamwork

History has shown that humans in society need to cooperate with each other in their lives whether to live, work, or even to play (West, 2004). As an organization's structure grows and becomes more complex, the need for groups of people to work together becomes more vital (West, 2004). The nature of engineering problems requires engineers to work in groups. Lumsdaine et al. (1999) argued that "with today's knowledge explosion, it is no longer possible for a single person to know all the data connected to a problem" (p. 93). At the college or university level, engineering design curriculum has been designed for students to practice working in a group to solve engineering design problems.

To better inform the conceptual framework, theoretically, the hypothesis is that if students have good engineering knowledge, high creative ability, and good interaction among team members, then excellent and creative design solution can be expected.

Definition of Terms

The following terms were operationally defined for the purpose of this study:

1. *Senior design students* – students in College of Engineering, Colorado State University who are enrolled in Engineering Design Practicum I (MECH486A) and Engineering Design Practicum II (MECH486B) in two consecutive semesters. These courses act as the capstone for the Mechanical Engineering bachelor degree program.
2. *Senior design team* – a group of students who have been assigned a specific engineering design task in MECH486A by a group of instructors and graduate teaching assistant. They remain in the same group and continue the same design task in MECH486B in the following semester.
3. *Creativity Index score* – an individual score from the Torrance Tests of Creative Thinking (TTCT).
4. *Composite creativity score* – the average creativity score of the total number of students in a team. (e.g., If there are five members in a group, the individual creativity test scores from each student will be added and averaged to get the composite creativity score for that particular group). The composite creative score is needed in this study as an average for comparability of different size groups.
5. *Team interaction score* – the pre and posttest mean difference average on Team Climate Inventory (TCI) score to represent growth or decline of team interaction within each team.

6. *Senior design outcome* – could be a real functional product, a prototype, or an engineering solution. The team projects list involved in this study can be found in Appendix A.
7. *Engineering course GPA* – the cumulative grade point average (GPA) of all prerequisite or required engineering courses for Mechanical Engineering Senior Design Practicum (MECH486A/B) including mathematics, physics, chemistry, and engineering sciences courses. The engineering course GPA was used as a proxy measure to represent students engineering knowledge in this study.

Assumptions

An exploratory quantitative non-experimental correlational research design was used in the study. There was no intervention involved in the study and the researcher did not have control over the independent variables. The following assumptions were made about the study, its context, and the classroom.

1) The sample studied was representative of the total population of Mechanical Engineering and Engineering Science students who are enrolled in Engineering Design Practicum I (MECH486A) and Engineering Design Practicum II (MECH486B) in sequence for two semesters (from fall 2011 until spring 2012) in the College of Engineering at Colorado State University. However, mechanical engineering and engineering science students were treated as one group because they follow virtually the same curriculum. The design teams remained the same through MECH486A and MECH486B.

2) No major changes were made in the curriculum design and instruction throughout the two consecutive semesters. Additionally, the researcher assumed that any changes did not affect the findings of this research.
3) The demographics of the participants are homogenous especially in their academic backgrounds and achievement. All participants were Mechanical Engineering and Engineering Science students with cumulative GPAs above 2.00.
4) Because the researcher had no control over group assignment, the researcher assumed the sample is normally distributed among the groups.
5) Since this study involved multiple instruments, the researcher assumed that all the students completed the creativity tests and team interaction questionnaire seriously and honestly. This led to the assumption that the test scores and team interaction scores are normally distributed.

Delimitations

This study was conducted at one university with Mechanical Engineering and Engineering Sciences final year students – who are enrolled in MECH486A in fall 2011 and MECH486B in spring 2012. The findings are limited and only true for this specific setting. Therefore the researcher has no interest to generalize the findings to a larger population like other courses, programs, or universities.

General Limitations

While specific research design limitations are discussed in detail in Chapter 3, the general study limitations follow. This study was conducted in two consecutive semesters.

Two main instruments including the Torrance Tests of Creative Thinking (TTCT) (Figural Form A) and the adapted Team Climate Inventory (TCI) questionnaire were administered in this study. Each instrument was administrated at different times during the period of the study to limit fatigue among participations in the study and prevent study attrition. In addition, the instrument for assessing the senior design final outcome or solution was reviewed by content and measurement experts and did not undergo pilot testing.

The cooperation of the course professor was crucial to achieve 100% participation and contribution from the participants. Since there was a creativity test and team interaction questionnaire administered in this study, the cooperation of the course Professor was needed to allocate some time during the class period for the researcher to administer the test and distribute the questionnaire.

This study was conducted from August 2011 to April 2012 in the Department of Mechanical Engineering at Colorado State University. For the purpose of this study, the sample was selected from students enrolled in the fall 2011 semester of Engineering Design Practicum I (MECH486A, *N* = 99 students). No students dropped out of MECH486A and MECH486B during the period of the study.

Researcher's Perspective

The researcher's background as an educator working with engineering students and pre-service engineering and technology teachers at one of Malaysia's higher education institutions has driven him to explore creativity and team interaction in engineering design. The researcher's colleagues often say how important it is for students to be creative and communicate well among their peers in solving engineering design problems. Additionally, the researcher has encouraged students to work in teams and come up with creative solutions or products for engineering problems. However, when it comes to creativity and teamwork assessment, he has experienced difficulties in terms of what kind of creativity and teamwork characteristics should be measured and how these can be measured.

As a technology and engineering educator, the researcher believes that students' knowledge, skills, attitude, etc. can be measured. In most cases, academic achievement was used as a benchmark by employers in hiring new workers. Students' academic achievement are used to represent their basic knowledge and applied skills required for a specific job with the employer (Casner-Lotto & Barrington, 2006). In engineering industries, besides good academic achievement, it has been reported that employers are also interested to know their newly hired employees' creativity and teamwork skills (Kemper & Sanders, 2001).

The general research interest of the researcher is on test and measurement especially in engineering education. It is one of the researcher's goals to contribute and publish his work by introducing research methods that can be used to assess skills such as creativity and teamwork among engineering college students especially in engineering design. The most well-known American Society for Engineering Education (ASEE) has two specific divisions called Education Research and Methods (ERM) and Design in Engineering Education (DEE) where the researcher can publish his work. The main objectives of ERM division is the "dissemination of knowledge on learning and teaching; encouragement of efforts to improve instruction through development of innovative materials and techniques, sound instructional design, and improved evaluation methodology; and enhancement of the status of teaching in the university" (American Society of Engineering Education, 2011, p. para. 18). While the main objective of DEE is to address design education issues across every engineering discipline.

The researcher acknowledges that this study was conducted in a setting with a different culture and different educational system compared to what he has experienced in Malaysia. He considered this an advantage for his professional growth as he had an opportunity to observe a new content that helps inform a new perspective on engineering education.

CHAPTER 2: REVIEW OF LITERATURE

"It would seem that while creativity is especially difficult to define, it is something that we can recognize when we see it" – Hennesey (2005)

The constructs of engineering knowledge, team orientation, and creativity are unique and have their own body of knowledge. Therefore the purpose of this literature review is to bring perspectives from each of these communities to inform this study. The literature review section will be guided by eight questions that relate to each construct:

a) What is creativity?
b) What is measured in creativity?
c) How is creativity measured?
d) What is engineering knowledge?
e) What is engineering design?
f) How important is teamwork in engineering design?
g) Why is creativity important to the engineer?
h) What are the relationships between creativity and engineering design?

The organization of the literature review will be around the constructs presented in Figure 1.1 illustrated in Chapter 1. Therefore, creativity as a whole and many of its sub-elements will be reviewed; engineering knowledge and most of its sub-elements, such as the engineering design process will be reviewed; and team interaction and its elements will be reviewed. These areas will make this review from more than one field and body of knowledge, and will be presented to provide grounding for greater understanding of the topic.

Creativity

Genius, invention, talent, and creativity are the highest levels of human performance (Eder & Hosnedl, 2008; Kerr & Gagliardi, 2004; Sawyer, 2006), “and yet most critical to human advancement” (Kerr & Gagliardi, 2004, p. 2). Conversation about creativity began in 1950 when an American psychologist, Joy Paul Guilford from The University of Southern California, addressed the importance for psychology researchers to conduct research related to creativity. Before then, psychologists’ main tool for measuring human creativity was the IQ test (Clapham & Schuster, 1992; Guilford, 1950), but this meant psychologists were conflating creativity with intelligence, arguing that IQ tests measure a person’s performance on several indicators including abstract problem solving ability (Flynn, 1987). Guilford (1950) believed that the nature of creativity itself was difficult to describe and measure. For example, even in an equal environment with equal opportunity, two different people have different creative productivity.

Since the 1950s, psychologists have debated what IQ tests really measure (Flynn, 1987). Does intelligence equate to creativity? Guilford (1950, 1987) and Sternberg (2001) argue that creativity goes beyond human intelligence. Guilford (1950, 1987) defined creativity as a process or activity, which includes inventing, designing, contriving, composing, and planning. The basic approach for inventing or designing is using imagination to produce something valuable, realistic, and/or accepted (Finke, Ward, & Smith, 1992; Guilford, 1987). Contriving and composing in the creative process involves working out how to engineer or manufacture the product. In generating a new idea, more creative thinking is required and the thinking needs to be organized into a larger, more inclusive pattern (Guilford, 1987). It is important to acknowledge the importance of planning stages in order to complete the task successfully. People who are able to demonstrate their capability in all of these types of activities to a distinct degree are recognized as being creative (Guilford, 1950, 1987).

It is important to recognize that one person’s creative productivity differs in performance from time to time (Guilford, 1950). A person’s creative productivity is dependent upon major behavior traits other than abilities (e.g., motivational factors, temperament factors, etc.) (Guilford, 1987). Guilford (1987) argues that most “people believe that creative talent is to be accounted for in terms of high intelligence or IQ. This conception is not only inadequate but has been largely responsible for the lack of progress in the understanding of creative people” (Guilford, 1987, p. 44). In addition, Clapham and Schuster (1992) reported that research has repeatedly shown low correlations between IQ and creativity measures. In his review of creativity literature, Wallach (1971) summarizes:

> Within the upper part of the intellective skill range, intelligence test scores and grades on standard academic subject matter are not effective signs as to who will manifest the strongest creativity attainments in nonacademic contexts. Empirical documentation of this relative unpredictability of creativity criteria from intellective skills data suggests that a separation between these two realms genuinely exist (p. 30).

Generally, it has been argued that the concept of creativity is too loosely defined (Goldenberg, Mazursky, & Solomon, 1999; Kaufmann, 2003) and the debate seems still ongoing (Sternberg & Lubart, 1999). However, for the purpose of this study, the researcher will describe creativity as a process that relates to individual and group performance toward accomplishing the senior design task or project.

Perspectives on Creativity

For the purpose of this study, the perspectives on creativity in psychology and the arts as well as in engineering and technology are reviewed to highlight the similarities and differences of creativity applied in these three fields.

Psychology perspective

Despite difficulties in defining creativity, the researcher will refer to the definition of creativity from three psychologists, Guilford (1950), Torrance (1962), and Sternberg (1999) in this study. These three psychologists have defined creativity as an outcome and a process. Guilford (1950) asserts:

> [Creativity is] the abilities that are most characteristic of creative people. Creative abilities determine whether the individual has the power to exhibit creative behavior to a noteworthy degree. Whether or not the individual who has the requisite abilities will actually produce results of a creative nature will depend upon his motivational and temperamental traits. (p. 444)

Guilford's definition of creativity was based on his research interests in human intelligence, and his concept of divergent thinking was a result of his research on developing the structure-of-the-intellect (SI) model. While researching creativity, Guilford identified numerous intellectual abilities such as fluency, flexibility, originality, and elaboration, which have collectively been labeled as parts of divergent thinking. Meanwhile, Torrance (1962) argued:

> [Creativity is] the process of sensing gaps or disturbing, missing elements; forming ideas or hypotheses concerning them; testing these hypotheses; and communicating the results, possibly modifying and retesting the hypotheses. (p. 16)

Torrance's definition of creativity was more focused on the process involved in creativity. He reviewed at least 50 definitions of creativity and wanted a definition that would describe creativity as a very natural process, within the reach of everyday people in everyday life, and yet possible at any age. After defining creativity, Torrance designed activities to measure creative thinking abilities to fit his definition. Torrance adopted Guilford's ideas of divergent thinking and developed a test called the Torrance Tests of Creative Thinking (TTCT). This test was originally used to measure creativity within four intellectual abilities that Guilford identified in school-age children. The four intellectual abilities are fluency, flexibility, originality and elaboration. These will be discussed later in this review.

Finally, Sternberg and Lubart (1999) define creativity as "the ability to produce work that is both novel (i.e., original, unexpected) and appropriate (i.e., useful, adaptive concerning task constraints)" (p. 3). The Sternberg and Lubart (1999) definition was influenced by Guilford's (1950) and Torrance's (1962) definitions of creativity. Sternberg and Lubart believed creativity was comprised of six basic elements: intelligence, knowledge, thinking styles, personality, motivation, and environment. These elements will be discussed later in this literature review section.

It has been recognized that Guilford's theories of the creative process had a great impact upon the development of creative thinking industry. Both Guilford (1950) and Torrance (1974) have suggested a creative individual should possess the types of abilities measured by tests of divergent thinking. Torrance (1962, 1968, 1974) has provided a significant contribution in terms of objectively evaluating creative talent on a standardized measure. Guilford (1950), Torrance (1962), and Sternberg (1999) agree upon three aspects of creativity in which the originality, appropriateness, and the production of works are of value to society.

Artistic Perspective

Compared with other fields, artistic creativity is one of the most widely studied fields in the area of creativity (Cropley & Cropley, 2005). Alland (1977) expressed artistic creativity as creativity articulated in any aspect of the arts, including visual art, music, literature, dance, theatre, film, and mixed media. Cowdroy and Williams (2006) reported that the literature in creative arts has distinguished various types of artistic creativity based on the outcome (e.g., painting, design, composition, script for a play) and some of them coupled two or more creative fields (e.g., play-writing and acting) to form a third art form, such as drama, music, etc.

Cowdroy and Williams (2006) define artistic creativity as the uniqueness or excellence found in the outcome "whether or not higher-order intellectual activity is indicated (e.g., in news photography, medical illustration)" (p.102). Gluck, Ernst, and Unger (2002) argue that in most cases, an artist did not offer any common measures for assessing creative products in their field. Creativity in art always results in something that is different in an interesting, important, fruitful, or other valuable way.

Creativity from the artistic view is very subjective and does not seem to have a clear reason (Schmidhuber, 2006; Tomas, 1958; Weisberg, 2006). For example, creativity in art "is not a paradigm of purposive activity" (Tomas, 1958, p. 2). Although an artist targets a specific idea in his work, the creative artist may not initially know what his target or outcome will look like (Tomas, 1958). Therefore, it is hard and may be impossible to investigate the thought process underlying artistic creativity (Weisberg, 2006). From the artistic perspective, people do not judge creative art work unless they believe it to be original (Tomas, 1958).

Engineering and Technology Perspective

Literature on creativity in the field of engineering and technology is inadequate when compared with other fields (Thompson & Lordan, 1999). Therefore, it is a challenge to find a good definition of creativity from a technology and engineering perspective. Despite the challenge, the researcher managed to find creativity defined by Drabkin (1996) as “the ability of human intelligence to produce original ideas and solutions using imagination” (p. 78). Lumsdaine et al. (1999) defined creativity as “playing with imagination and possibilities while interacting with ideas, people, and environment thus leading to new and meaningful connections and outcomes” (p. 9). Cropley and Cropley (2005) proposed a four dimensional model for creativity in engineering and technology: (a) relevance and effectiveness, (b) novelty, (c) elegance, and (d) generalizability. Relevance and effectiveness refer to how closely matched the product solution is to the problem it was intended to solve. Novelty refers to originality and surprisingness of the product. Elegance refers to the product’s appearance (e.g., beautiful, simple), and it is considered a bonus if the new product design is cost effective. Finally, generalizability means the product is able to be and is accepted into a larger use or is flexible for adoption. Elegance and generalizability were considered as value-added to the creativity of the product, so they are lower in the hierarchy of the model.

Cropley and Cropley (2005) explain that when two of the four dimensions in their model are present in a product, it is possible to discuss creativity, especially when the two dimensions present are relevance and effectiveness and novelty. For example, some people might say that the iPhone® designed by Apple has an elegant design because it is simple. In terms of functionality, an iPhone® is easy to use and the consumer does not have to be smart or savvy in order to use it. In terms of generalizability, an iPhone$^{®}$ is very accepted in any part of the world. It is a bonus if people can buy an iPhone® at an affordable price.

In engineering, creative products or creative outcomes are often described as having three primary characteristics including novelty, value, and surprisingness (Nguyen & Shanks, 2009). Cropley and Cropley (2005) have gone into more detail about the characteristics of creativity in engineering. Unlike fine arts, Cropley and Cropley (2005) believe that engineering creativity is different. Engineering creativity can clearly be seen through outcomes including product, device, or system being developed by engineers. Within the literature, there are various ways to define creativity; perhaps the definition differences are due to the unexpected ideas that appear among creative people, together with little sensible attention paid to how their creativity grows on the part of those who have the ideas (Niu & Sternberg, 2001). In this section, the researcher has reviewed the perspective of creativity from three different fields including psychology, the arts, and engineering and technology. It is important to acknowledge that this study specifically looks at creativity from the engineering and technology perspective. However, this raises a significant question regarding both the relationships and the differences between creativity, innovation, and invention.

The Distinctions Among Creativity, Innovation, and Invention

In most engineering design textbooks, it is recognized that there is strong connection between design and creativity. Cross (2008) stated that the design methods or approaches were meant to help inspire a person’s or a designer’s creative thinking.

However, a clear distinction between creativity, innovation, and invention has not been made, and scholars in engineering design continue to debate even the definition of creativity. The word ‘invention’ causes yet more trouble since there was no fully acceptable definition on creativity (Kemper & Sanders, 2001).

Creativity

Creativity has been defined as the capability of generating ideas that are original or unusual and appropriate (Haik, 2003; Madsen et al., 2004; Sternberg & Lubart, 1999). In plain language this means the ability to create. People often associate creativity with the arts, but in fact it is a quality useful in all kinds of situations. It is all about the ability to think differently. For example, in World War I, the British officers in command showed no creativity whatsoever in their strategy, and therefore just kept sending more and more soldiers into battle field to be blown up. It was the Royal navy who suggested the creative idea of the tank, and at that time it seemed ridiculous or a silly idea (Harris, 1995).

Innovation

Innovation is about producing something better, producing more effective products, processes, services, technologies, or ideas that are accepted by markets, governments, and society. Madsen et al. (2004) define innovation as “a process of transforming a creative idea into a tangible product, process, or service” (p.137). Couger, Higgins, and McIntyre (1990) define innovation as a process of implementing the creative idea.

Innovation is the improvement or adaptation of an existing artifact in order to repurpose it for something new. In other words, “innovation is about improving the quality of a specific thing (artifact) and allowing for more and better choice" (Madsen, et al., 2004, p. 137). Innovation can also be the combination of existing technologies, for example, a hybrid vehicle. The history of the automobile begins as early as the mid-1700s with the creation of steam engine automobile. In the early 1800s, the first vehicle powered by an internal combustion engine running on fuel gas was introduced, which led to the introduction of the modern gasoline or petrol fueled internal combustion engine in late 1800s. By the late 19th century, engineering advances led to the widespread adoption of the internal combustion engine in a variety of applications. Due to the energy crisis in the 1970s, car manufacturers recognized the need to find ways to reduce the gas or petrol consumption in vehicles, yet not until the 21st century was a commercially available hybrid car introduced. A hybrid car is a vehicle that uses two or more separate power sources to move the vehicle, a combination of an internal combustion engine and one or more electric motors. Innovators merged the two technologies of the internal combustion engine and the electric motor to move a vehicle.

Invention

Invention however, can be defined as "the creation of something that has never been made before and is recognized as the product of some unique insight" (Sloane, 2010). Sloane (2010) states:

> If you have a brainstorm meeting and dream up dozens of new ideas then you have displayed creativity but there is no innovation until something gets implemented. Somebody has to take a risk and deliver something for a creative idea to be turned into an innovation. An invention might be a product or device or method that has never existed before. So every invention is an innovation. But every innovation is not an invention (para. 2)

Inventions often integrate the limits of human knowledge, experience, and capability in producing a product that has not seen before. Referring back to the innovation example, the steam engine was invented in mid-1700s. In that era, the steam engine was considered a great invention because the world had not seen such a machine used for transportation. New knowledge often leads to new technologies and new ways of doing things. Such new knowledge led to the invention of the internal combustion engine in early 1880s.

In summary, both innovation and invention begin with a creative process (Berkhout, Hartmann, Duin, & Ortt, 2006; Couger, et al., 1990). However, innovation differs from invention, as innovation refers to the use of a new idea or method, while invention refers more directly to the creation of the idea or method itself. In a sense, engineers are inventors, though inventors do not necessary need to be engineers (Moubayed, Bernard, & Jammal, 2006).

Creativity as Human Performance/Achievement

Although creativity is recognized as one of the highest levels of human performance, scientists and researchers have not paid much attention to it; in fact the area of creativity was declared a scientific “disaster” (Kaufmann, 2003; Sawyer, 2006). Sawyer’s and Kaufmann’s statements were based on the limited numbers of studies related to creativity. More recently, researchers have come to understand that creativity requires understanding two main categories of factors: individual inspiration and social factors. Social factors are collaboration, network of support, education, and cultural background (Sawyer, 2006). To make this point, Sawyer (2006) states most of the products created in the modern era of mass production are created by groups of people in organizations, and this process could inspire entire societies (Sawyer, 2006).

People are capable of applying their intellect in different ways by using divergent thinking, and this divergent thinking is associated with human creativity (Guilford, 1950). Divergent thinking skills represent how easily an individual can produce many ideas, which is called ‘fluency’. Ideas that correspond to many different lines of thinking are called ‘flexibility’ (Hocevar, 1979).

Guilford (1950) believed that creativity provides capabilities not possible with just intelligence. Creativity will enhance research and development of a field or discipline that can drive a nation toward industrialization. According to Dekker (1995), at the level of the individual engineer, this means that creativity is essential for a successful engineering career. “Creativity is no longer seen as purely the domain of aesthetes and intellectuals concerned with questions of truth and beauty, but also as a pathway to national prosperity and a means for making the nation strong and safe” (Cropley & Cropley, 2005, p. 170).

In this section, the researcher has reviewed the general aspect of creativity, including the definitions; the distinctions between creativity, innovation, and invention; and creativity as human performance. This review led to the following section that discusses what is measured in creativity.

Multidimensionality of Creativity

Though finding a unified definition of creativity is difficult, finding a valid and accepted measurement model for creativity is even more illusive. Treffinger (1986) purports that there is no single creativity assessment tool commonly accepted since there is still no ‘general theory’ of creativity that has been developed. It has been agreed however, that measurement of creativity can be divided into four categories: (a) product, (b) process, (c) person, and (d) context (MacKinnon, 1970; Mooney, 1963; Rhodes, 1961). The product category focuses on describing the nature of the creative product itself (Besemer, 2006). This inquiry often conceptualizes creativity as how unique the product is. The process category relies on a cognitive approach by exploring the role of factors such as knowledge, memory, and interest (Runco & Chand, 1995). The person category focuses on describing personality characteristics of the creative individual, including experiences (inner self and outer world), knowledge and action, and courage (MacKinnon, 1970). Finally, the environment or situation category focuses on examining the external forces, which press on the individual to be creative, such as social dynamics, culture, and climate (Amabile & Gryskiewicz, 1989).

Problem Finding and Evaluation

Brown (1989) acknowledges both ‘problem-finding’ and evaluation are components of creativity, stating problem finding is a more crucial element of creativity than problem solving. “Creative individuals’ problem finding actively refers to their looking for discrepancies or something they do not understand” (Brown, 1989, p. 23). Problem finding would emphasize individuals’ seeking the right questions as a critical first step in producing a creative solution. Henle (1974) argues that asking the correct questions may be the most creative element of the whole creative process. Brown (1989) also discussed longitudinal study of prospective artists in the past by Getzels and

Csíkszentmihályi (1976) examining the relationship between problem finding and subsequent evaluations of art students' drawings. Getzels and Csíkszentmihályi (1976) found a positive correlation between the problem finding total scores in the drawing exercise and the success as an artist.

Brown (1989) believed that evaluation is a virtual model of problem solving. Brown shared his students' frustrating experiences attempting creative problem solving by their continual failure to evaluate potential solutions. Brown (1989) argues that the incorrect solution should lead individuals to a further search that might yield more creative and appropriate solutions. Furthermore, Campbell (1960) suggests that the potential solutions may be evaluated with a number of criteria, and a creative problem solver may be able to keep track of and relate more criteria at one time.

Creative Process

Unsworth (2001) has developed a Matrix of Creativity Types as shown in Table 2.1. The Unsworth (2001) matrix was driven by two questions that motivated the creative process: (a) Why do people engage in creative activity, and (b) What is the initial state of trigger? (pp. 289-290).

Table 2.1

Matrix of Creativity Types (Unsworth, 2001)

Creativity dimension	**Factor**	**Description**	**Types of creativity involve**
Why? - Idea generation. The driver behind the engagement.	Internal drive	Self-determination	Proactive creativity Contributory creativity
	External drive	Job or task description	Expected creativity Responsive creativity
What? - The degree of problem findings needed.	Closed problems	The method for solving the problem is known	Responsive creativity Contributory creativity
	Open problems	Participants are required to find, invent, or discover the problems	Proactive creativity Expected creativity

According to Unsworth (2001), there are two factors which influence idea generation: internal driven and external driven. The internal driven factor identifies an individual experience as the initiator of creative behavior. For example, an engineer’s self-motivation to accomplish his project goal successfully represents an internal driver for creativity. Meanwhile, the external driven factor refers to a situation, working environment, or a certain task that needs to be performed, such as is found at the engineer’s job, as the driver for creativity. The second aspect is related to the categorizing of the problem, whether it is an open or closed problem. An open-ended problem requires the individual to explore and discover the problems before being able to come up with the appropriate solution. A closed problem deals with a known problem type and the solution may be much more direct.

Unsworth (2001) also discovered four types of creativity that emerged from the matrix: responsive creativity, expected creativity, contributory creativity, and proactive creativity. Unsworth (2001) stated that responsive creativity is “external driven, closed-problem fields” in which “the participant responds to the requirements of the situation and to the presented problem” (p. 291). Expected creativity is “creativity that is brought about via external expectation - but with self-discovered problem” (p. 292). The third type, contributory creativity, is “a type of creativity that is self-determined and based upon a clearly formulated problem” (p. 292). The last type, proactive creativity, “occurs when individuals, driven by internal motivators, actively search for problems to solve” (p. 292).

Process-oriented Creativity

One of the instruments used to measure process-oriented creativity is the Torrance Tests of Creative Thinking (TTCT) developed by E. Paul Torrance in 1966. The TTCT is used to measure cognitive processes (Almeida, Prieto, Ferrando, Oliveira, & Ferrandiz, 2008; Cooper, 1991). The TTCT is “the most popular method for the assessment of creativity” (Lissitz & Willhoft, 1985, p. 2), and continues to be useful in the identification of highly creative students and in the nurture and development of creative thinking skills (Kim, 2011). The TTCT is generally “used as a group-administered criterion to assess the effectiveness of assorted curricula and teaching methodologies” (Lissitz & Willhoft, 1985, p. 2). The TTCT was based originally on the Guilford (1956) divergent process dimensions with its four categories of fluency, flexibility, originality, and elaboration (Lissitz & Willhoft, 1985). Fluency is the number of relevant responses a person provides given a problematic prompt; flexibility is the variety of solutions and how diverse they are; originality refers to the unique nature of ideas; and elaboration is the depth of the description given for each solution (Torrance, 1974). Additionally, the TTCT has shown that all four creativity constructs cannot be measured independently because they correspond with one another as a part of creative process (Hocevar, 1979; Torrance, 1974). Table 2.2 shows the TTCT creative dimensions in divergent thinking processes.

Table 2.2

Torrance Test of Creative Thinking (TTCT) creative dimension (Torrance, 1974)

Creative dimension	**Definition / Description**
Fluency	The ability to produce a large number of ideas with words
Flexibility	Ability to produce a variety of kinds of ideas, to shift from one approach to another, or to use a variety of strategies
Originality	Ability to produce ideas that are away from the obvious, common place, banal, or established
Elaboration	The amount of detail in the responses

The TTCT is made up of two test forms, the Verbal Form and Figural Form, and includes seven verbal subtests and three figural subtests, which are used to assess four dimensions in creativity: fluency, flexibility, originality, and elaboration. TTCT forms have two different sets: A and B. Simpson (2010) reports that the TTCT has a high rank in content, concurrent, and construct validity. The test retest reliability (*r*) was reported to be significantly high based on the TTCT Figural tests (Simpson, 2010). Simpson's longitudinal study between two groups found that in the area of fluency, the test retest reliability was ranged from .96 and .99. In the area of originality, the test retest reliability ranged from .91 to .99. Elaboration had test retest reliability ranged from .95 and .98.

Creative Product Assessment

Besemer and O’Quin (1999) developed the Creative Product Analysis Matrix (CPAM), a three-dimensional model of creativity in products as illustrated in Table 2.3. In defining product creativity, Besemer and O’Quin (1987) emphasized novelty, resolution, and elaboration and synthesis and ascribed novelty to a product with originality and surprisingness. “Novelty (the first dimension) is a critical component of creativity in products”(Besemer & O'Quin, 1999, p. 288). The second dimension, resolution, is based on the usefulness or functionality of the product. Resolution refers to the value, logic, usefulness, and understandability of the product, while elaboration and synthesis, the third dimension, “considers the perceived attributes of style in the product’s production” (Besemer & O'Quin, 1999, p. 288). Elaboration and synthesis weighs how elegant, organic, and well-crafted the product is. Based on the CPAM model, Besemer and O’Quin (1999) developed the Creative Product Semantic Scale (CPSS) to measure creativity in product.

Table 2.3

Creative Product Analysis Matrix (CPAM) dimensions (Besemer & O'Quin, 1999)

Dimensions	Description	Facet
Novelty	Newest in materials, processes, concepts, and methods of making the product	Originality Surprise
Resolution	How well the product works or functions	Logical Useful Valuable Understandable
Elaboration and Synthesis	Stylistic component of the product	Organic Well-crafted Elegant

The CPSS was formally developed in 1986 when preliminary testing of a series of bipolar adjective scales began (Besemer & O'Quin, 1986). The development of the final instrument required several years to complete. It began with 80 items in CPAM (Besemer & O'Quin, 1986) and was reduced to 55 items in CPSS. The original 55 items of CPSS were then reduced to the final 43 items (Besemer, 1998). The 43 criteria in CPSS are scored using a semantic-differential rating scale (e.g., surprising-unsurprising, logical-illogical, elegant-inelegant).

The internal consistency reliabilities (Cronbach's alphas) for the measurement of novelty ranged from .69 to .86. The Cronbach's alphas for resolution and elaboration were reported to range from .79 to .85 and .80 to .87, respectively (Besemer, 1998; Besemer & O'Quin, 1999).

The other tool that can be used to assess the product outcome is the Student Product Assessment Form (SPAF) developed by Sally M. Reis in 1981 as part of her dissertation research with her advisor Joseph Renzuli. The SPAF was developed to aid teachers in assessing the quality of student products in gifted and talented programs according to nine criteria (Reis, 1981). The nine items assess both individual criteria as well as the overall excellence of the product. Items one through eight are divided into the following three related categories:

> a) The Key Concept. This concept is always presented first and is printed in large type. It should serve to focus the rater's attention on the main idea or characteristic being evaluated.
> b) The Item Description. Following the Key Concept are one or more descriptive statements about how the characteristic might be reflected in the student's product.
> c) Examples. In order to help clarify the meaning of the items, an actual example of student work is provided. These examples are intended to elaborate upon the meaning of both the Key Concept and the Item Description. The examples are presented in italic following each item description. (Reis, 1981, p. 41)

Item nine includes seven components involving an overall assessment of the product and covers the product values and characteristics.

Reis reported that the validity and reliability of the SPAF have been proven (Reis & Renzuli, 2004). An expert review for content validity of the SPAF has been conducted by 20 experienced teachers of gifted and talented learners (Reis, 1981; Reis & Renzuli, 2004). The interrater agreement of the SPAF was determined in two separate phases. The first phase involved 19 experienced raters who rated a product of a first grader. The results were used to revise the SPAF. In the second phase, the revised SPAF was used to assess a second and third product; 22 raters were involved in this phase. Reis (1981) reported the agreement percentages on the second product were 100% and the third product were above 80%. The interrater reliability was generated involving 20 different products representing five different types: scientific, creative writing, social studies, audio visual, and interdisciplinary. Four experienced teachers were asked to rate the products. Reis used Ebel’s (1951) technique in Guilford (1954) to intercorrelate the ratings obtained from her four different raters. The totals of interrater reliability of the four raters were .99.

Although creativity has been considered complex in its nature, creativity measurement tools do exist and can help to quantify creativity. However, it should be recognized that different instruments may measure different constructs. Each construct needs to be clearly defined for the researcher to design an appropriate study to assess creativity in engineering design.

How is Creativity Measured?

There are numerous approaches used by psychological researchers to investigate creativity among human beings. The following seven approaches are described by Sternberg and Lubart (1999).

Mystical approach. This approach is tied to mystical beliefs. In the mystical paradigms, the “creative person was seen as an empty vessel that a divine being would fill with inspiration” (p. 5). From this view, “many people seem to believe that creativity is something that just does not lend itself to scientific study” (p. 5). For scientific psychologists, the construct of creativity is hard to explore using the mystical approach.

Pragmatic approach. The primary concern of this approach is to develop creativity, and the secondary concern is to understand creativity. The foremost supporters of this approach are Edward De Bono (lateral thinking) and Alex F. Osborn (brainstorming), and their concern is not with theory, but with practice. According to Sternberg and Lubart (1999), this approach lacks any basis or grounding in serious psychological theory. Of course, practice can work in the absence of theory but the effects of this approach are “often to leave people associating phenomenon with commercialization and to see it as less than a serious endeavor for psychological study” (p. 6).

Psychodynamic approach is the initial major 21st century theoretical approach to the study of creativity. This approach is based on the idea that creativity arises from the conflict between conscious reality and unconscious drives. Case studies of famous creators like Leonardo da Vinci are used to support this approach. Although this approach may offer some insights into creativity, it has been heavily criticized, and is not at the center of emerging scientific psychology for studying creativity.

Psychometric approach. Guilford (1950) proposed that creativity could be studied in daily topics with no eminent sample and with a psychometric method, using paper and pencil tasks. The divergent thinking tasks originally developed by Guilford have become the main instruments for studying creative thinking and have been adopted by many researchers like Torrance (1966). However, this approach of measuring creativity had both positive and negative impacts on the field. On the positive side, the tests aid research by providing a brief, easy to administer, objectively scorable instrument, which can be used to test ‘noneminent’ people. On the other hand, some researchers found that paper and pencil tests were insignificant and inadequate measures to assess creativity.

Cognitive approach. The goal of the cognitive approach is to recognize mental representations and processes underlying creative thought. This approach involves two main processing phases: the generative phase and exploratory phase of the individual

(Finke, et al., 1992). In the generative phase, an individual constructs mental representations, which have properties that promote creative discoveries. In the exploratory phase, the creative discoveries are used to come up with creative ideas.

Social-personality approach. Working in parallel with the cognitive approach, the social-personality approach focuses on three sources of creativity: personality, motivation, and sociocultural environment (Sternberg & Lubart, 1999). In this approach, proposals regarding self-actualization and creativity can be considered within the personality tradition. Maslow's theory on the hierarchy of human needs explains how fulfilled a person is with regard to basic needs, which can help lead a realization of his or her full potential. Research has shown that when creative students are taught and assessed in ways that value their creativity abilities, their academic performance improves (Sternberg, Ferrari, Clinkenbeard, & Grigorenko, 1996).

Confluence approach. The confluence approach was developed by Sternberg and was based on the investment theory. The confluence approach assumes creative people are willing and able to pursue unknown or unfavorable ideas that have great potential even when they encounter or face the resistance. This approach used tasks such as writing short stories with unusual titles, drawing pictures with unusual themes, devising creative advertisements for boring products, and solving unusual scientific problems. Through the investment theory, Sternberg suggests that creativity requires intellectual abilities (synthetic ability, analytic ability, and practical-contextual ability), knowledge about the field, styles of thinking (e.g., thinking in novel ways, thinking globally as well as locally, etc.), personality attributes (e.g., self-efficacy, willingness to overcome obstacles, sensible risk taking, and tolerance for ambiguity), motivation (intrinsic, task oriented), and a supportive environment (e.g., a forum to discuss and propose ideas).

Based collectively on all these approaches, scholars in creativity research agree that a multi-faceted method of looking at creativity can be developed. In this study the researcher used the psychometric approach in assessing students' creativity, although there was an argument related to format and the way the approach is administered. However, through the literature, scholars agreed that psychometric testing is the most popular and worthy approach used in creativity research (A. J. Cropley, 2000).

Measuring Creativity in Engineering Education

In engineering education, creativity has become a vital factor in good engineering practice (Cropley & Cropley, 2005). At the individual level of a practicing engineer, creativity has become an important factor for a successful career (Dekker, 1995). Creativity in engineering can be seen through products or systems that perform tasks or solve problems, which will be referred to later as functional creativity. Engineering creativity is a product of creativity with a purpose (Cropley & Cropley, 2005).

Cropley and Cropley (2005) conceptualize engineering creativity in two fundamental categories: (a) functional creativity and (b) latent functional creativity. Functional creativity refers to final products as solutions to problems; it is "driven by specific functional purpose" (Cropley & Cropley, 2005, p. 181) that is significant and effective in a specific context. The products of latent functional creativity are characterized by novelty without a specific functional purpose, although the novelty of the product may become significant and effective when the right situation occurs.

Nguyen and Shanks (2009) have purported that creativity might be understood using a set of dimensions including creativity elements (product, process, people, domain, and socio-organizational context), creativity levels (individual up to the societal level), and creativity loci (production and recognition, and adoption and diffusion). Cropley (2000) defined and summarized four dimensions and elements that can be used to test creativity including product, process, motivation, and personality or abilities. Table 4 can be useful for understanding on what dimensions creativity can be measured and elements involved in each dimension to be considered.

Table 2.4

Four dimensions and elements to test creativity.

Test defined elements of creativity by dimension			
PRODUCT	**PROCESS**	**MOTIVATION**	**PERSONALITY/ ABILITIES**
• Originality • Relevance • Usefulness • Complexity • Understandability • Pleasingness • Elegance/Well-craftedness • Germinality	• “Uncensored” perception and encoding of information • Fluency of ideas (large number of ideas) • Problem recognition and construction • Unusual combinations of ideas (remote associates, category combination, boundary breaking) • Construction of broad categories (accommodating) • Recognizing solutions (category selection) • Transformation and restructuring of ideas • Seeing implications • Elaborating and expanding ideas • Self-directed evaluation of ideas	• Goal-directedness • Fascination for a task or area • Resistance to premature closure • Risk-taking • Preference for asymmetry • Preference for complexity • Willingness to ask many (unusual) questions • Willingness to display results • Willingness to consult other people (but not simply to carry out orders) • Desire to go beyond the conventional	• Active imagination • Flexibility • Curiosity • Independence • Acceptance of own differentness • Tolerance for ambiguity • Trust in own senses • Openness to sub-conscious material • Ability to work on several ideas simultaneously • Ability to restructure problems • Ability to abstract from the concrete

Note. Adapted from “Defining and measuring creativity: Are creativity tests worth using?” by Arthur J. Cropley, 2000, *Roeper Review*, 23 (2), p. 77.

Table 2.4 shows the four dimensions and elements in creativity tests reviewed by Cropley (2000) in a multi-faceted way. The four dimensions include product, process, motivation and personality/ability factors.

Product dimension. The product dimension included elements that relate to the artifact, for example, its originality, relevance, usefulness, etc. This product dimension is extremely relevant in support of this study because one of the dimensions is understanding the design outcome and looking at originality, relevance, and elegance of a particular product.

Process dimension. The process dimension of creativity defined by Cropley (2000) had elements like fluency of ideas, problem recognition and construction, transformation and restructuring of ideas, and seeing implications. These elements are all related to the creative process and have direct connection to the engineering design process.

Motivation dimension. The motivation dimension described by Cropley (2000) had elements like desire to go beyond the conventional, risk taking, preference for complexity, willingness to display results, and goal directedness. These elements pointed to the motivation dimension described by Cropley (2000).

Personality/abilities. Cropley (2000) further described the fourth dimension as personality/ability and these affective individual characteristics like independence, curiosity, openness to sub-conscious material, trusting one's own senses and being active in terms of one's imagination. These personality/ability traits show an individual's affective cognitive ability to tolerate, to manage ambiguity, and to think divergently.

These determinations were made by Cropley (2000) through analysis of the creativity tests.

In the creative product dimension, Copley analyzed two instruments: the Creative Product Inventory (CPI; Taylor, 1972; 1975) and the Creative Product Semantic Scale (CPSS; Besemer & O'Quin, 1999). Based on these two instruments, Cropley (2000) found there are twelve common elements that can be used to describe creative product, including originality, relevance, usefulness, complexity, understandability, pleasingness, elegance, and germinality. The CPSS was discussed in the earlier section of this review of literature and emphasized three constructs: novelty, resolution, and elaboration and synthesis of the developed product.

In the creative process dimension, Cropley reviewed numerous instruments, including TTCT (Torrance, 1974), the Remote Associates Test (RAT; Mednick, 1968), the Test for Creative Thinking (Drawing Production) (TCT-DP; Urban & Jellen, 1996), and the Creative Reasoning Test (CRT; Doolittle, 1990). Through his analysis, Cropley (2000) found ten common elements used to assess the creative process (see table 4).

In terms of personal factors, Cropley conducted an analysis on more than ten instruments that can be grouped into two categories – personality or abilities and motivation. Through his analysis he found eleven common themes that can be used in measuring personality or abilities such as active imagination, flexibility, curiosity, independence, etc. In the motivation dimension, Cropley (2000) found ten common themes used to assess a person’s motivation toward creativity, such as goal-directedness, risk-taking, etc. In reviewing the literature on measuring creativity and particularly the work of Cropley, direct relevance to the engineering design process is evident. The metaanalysis of the creativity instruments that Cropley reviewed strengthens the notion that the creativity tests are very consonant in nature with engineering practice when engaged in solving an engineering design problem.

In summary, the researcher has reviewed and responded to the first three questions that guided this literature review: definitions of creativity, the multidimensional nature of creativity, and how creativity is measured? The researcher also related how creativity is measured across multiple conceptions of creativity and linked some of the most useful to potential applications in engineering design. The need to assess creativity in engineering education still exists due to challenges faced by businesses to survive and succeed in the 21st century (Charyton, Jagacinski, & Merrill, 2008; Cropley & Cropley, 2005; Kemper & Sanders, 2001). Therefore, for the purpose of this study, the relationship between two creativity dimensions that has been discussed in this section will be examined including creative product and creative process. Specifically, what is the relationship between creative product and creative process, and how does creative process impact the creative product in engineering design?

Engineering

The grounding of engineering is situated within our effort to survive and to improve our situation (Oaks et al., 2000). The concept of engineering has existed since prehistoric eras as humans invented fundamental creations such as the pulley, lever, and wheel to construct pyramids (Oaks, et al., 2000). Each of these inventions is still reliable with the modern definition of engineering, using basic mechanical principles to develop useful devices/products.

The history of engineering can be divided into four main phases: Pre-scientific Revolution, Industrial Revolution, Second Industrial Revolution, and Information Revolution (Moubayed, et al., 2006; Rae & Volti, 2001; Wright, 2002). During the Pre-scientific Revolution, also known as Early Civilization Age, engineers advanced knowledge with lots of trial and error and intuition. Perhaps the most well-known inventors in this era were Leonardo da Vinci (1452-1519) and Isaac Newton (1642-1727). Leonardo Da Vinci was well known as a famous painter. He also was a visionary and idealistic person far beyond his time. Da Vinci came up with ideas of flying machine (Ornithopter Flying Machine), but it was never created. However, some experts (i.e., Ross, 1953) say that the modern day helicopter was inspired by Da Vinci's "Ornithopter" design. Meanwhile, Sir Isaac Newton was a scientist, mathematician, and inventor. Newton came up with the theory that 'gravity' was the reason objects fell to the earth and he was best known for his law of motion.

The Industrial Revolution extended from the 1800s through early 1900s. It was considered the first modern engineering era in scientific revolution. In this era, engineers changed from practical artists to scientific professionals and they began to use structural analysis and mathematical analysis in building structures. During this phase machines were invented and powered by steam engines. These inventions started to replace human power in most areas of production. During this revolution transition, traditional artists transformed to modern professional engineers.

The Second Industrial Revolution began when electricity, telecommunications, and mass production were introduced a century before World War II. In this era, engineers not only designed but also managed mass production and distribution systems.

The most well-known and greatest contributor during this era was Henry Ford, who introduced the vehicle mass production assembly line. During this era, engineering college curricula were established and graduate schools appeared. Many workshops turned into to research laboratories, and individual inventions were planned and organized into more systematic innovations (Rae & Volti, 2001).

The Information Revolution Age was established after the World War II. The Cold War between United States and Soviet Union and the Sputnik effect (the first successful satellite launch in world history) escalated the research and development (R&D) in all fields of science and technology (Neal, Smith, & McCormick, 2008). Investment in R&D became a major incentive for innovation. In a recent publication by the National Science Board (2012), the estimated expenditures on R&D worldwide increased from about 500 billion dollars in 1996 to almost 1,300 billion dollars in 2009 (NSB, 2012). During this era, more than twenty specific disciplines of engineering emerged (Moubayed, et al., 2006). In terms of engineering education, the National Science Board (2012) reported that the number of graduates in engineering with a bachelor’s degree has increased rapidly within eight years (2000 to 2008). This is true especially in China, where the numbers of undergraduate degrees awarded in engineering have increased from about 200,000 in 2000 to 700,000 in 2008 (NSB, 2012).

Engineering is a profession that requires knowledge of mathematics and natural sciences gained through learning, experience, and practice (Eide, et al., 2002). The engineering knowledge is then applied to product development or solutions. The Accreditation Board for Engineering and Technology (ABET), defines engineering as follows:

> Engineering is the profession in which a knowledge of mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind. (Oaks, et al., 2000, p. 31)

Based on the ABET definition of engineering, the role of engineers is to produce products and processes that impact people in daily life by inventing, designing, developing, manufacturing, testing, selling, and servicing product (Eide, et al., 2002; Oaks, et al., 2000; Wright, 2002). Kosky, Wise, Balmer, and Keat (2006) define an engineer as a creative person who "creates (i.e., designs) ingenious solutions to societal problems" (p. 3).

It is important to realize that engineering is not only about the machines and inventions that have been designed, but also about people. To fully understand and appreciate any of the engineering inventions, we need to study the people involved. In this section, the researcher introduced a few of the important stages composing the history and definition of engineering that lead to the discussion in the next section about modern engineering practice.

Modern Engineering Practice

According to Oaks et al. (2000), there are basic classifications of engineering professions common across disciplines. These include research, development, testing, design, manufacturing, and construction. Research engineers explore the fundamental principles of chemistry, physics, biology, and mathematics to overcome difficulties and make advances in the field. A development engineer bridges the gap between laboratory small-scale research and full-scale production. The responsibility of test engineers is to design and implement tests to verify the integrity, reliability, and quality of products before introduction to the public. The design engineer is responsible for providing the detailed specifications for a product. The design engineer uses knowledge of scientific and mathematical laws, together with experience, to generate the shape of a part to meet the specifications of the whole product. Their concern is how well the product will work by verifying whether the part and/or product meet reliability and national and international safety standards.

Looking to the future, Wright (2002) says that engineers will face huge challenges associated with complex world's problems. For example, engineers recognize that natural resources are limited and therefore they need to discover, develop, and utilize alternative sources of energy to replace the world's diminishing supplies of natural sources such as coal and petroleum (Wright, 2002).

Mechanical Engineering

Engineering fields have been characterized into four main branches: chemical engineering, civil engineering, electrical engineering, and mechanical engineering (Wright, 2002). In this study, the researcher is specifically focusing on mechanical engineering as the domain of the study. Oaks et al. (2000) believe that "mechanical engineering is the broadest-based discipline in engineering" (Oaks, et al., 2000, p. 28). For example, there are many systems and devices requiring mechanical engineering knowledge such as automobiles, trains, ships, air and space vehicles, engines, heating and conditioning systems, transmission mechanisms, radiators, gas and steam turbines, servomechanisms, mechatronics, pumps, and many more. Mechanical engineering knowledge deals broadly with power, how it is generated, and how it can be applied. Power affects the rate of change or motion. Power can be the change of temperature or change of motion due to outside stimulus. In general, mechanical engineers design and analyze systems for the manipulation of mechanical energy (Kosky, et al., 2006).

At the college level, the mechanical engineering curriculum structure has been designed to meet the industrial needs. For example, at Colorado State University (CSU), the four year curriculum has been design to provide both classroom learning and on-campus experiential engineering. During the first year at CSU, mechanical engineering students learn the basic fundamentals of the physical sciences, chemistry, physics, mathematics, and are introduced to the mechanical engineering profession and practice. In the second year, basic engineering courses including mechanics, thermodynamics, and introductory design are introduced. In the third year, engineering analysis and laboratory classes in mechatronics, mechanisms, thermal/fluids, heat and mass, and mechanics are studied. During the final year, students have a yearlong capstone design course. In this capstone design course, students work in a team, designing and/or solving engineering problems for the two academic semesters.

It needs to be recognized that the volume of knowledge that engineers need to learn and practice is increasing rapidly, faster than the engineering curriculum can adapt (Rugarcia, et al., 2000). Koskey et al. (2006) define five qualities of a good designer: (a) curiosity about how things work, (b) unselfishness, (c) fearlessness, (d) persistence, and (e) adaptability. It is impossible to teach engineering students everything they will need when they go to work. At the same time, globalization has influenced the skills required for engineers being hired by industry. Engineering graduates need to have sufficient engineering knowledge, and interpersonal and teamwork skills as well as problem solving, critical thinking, and creative thinking. These requirements often force the engineering education shift away from the traditional approach of delivery such as simple presentation or lecture toward the integration of knowledge and the development of critical skills that will help engineering graduates to become immediately productive in their future work (Kemper & Sanders, 2001; Rugarcia, et al., 2000).

Teamwork

Due to dynamic changes in organizations, the need for members of organizations to work in teams has become important. This change has led to "increased complexity in terms of team composition, skills required, and degree of risk involved" (Barker, Day, & Salas, 2006, p. 1576). The definition of a team has been widely recognized as a group or unit of people who are working together to accomplish a specific task (Barker, et al., 2006; Lorge, Fox, Davitz, & Brenner, 1958). Besides having required specific skills such as management and judgment or decision making, team members are expected to handle risk in solving a problem.

There are many factors that contribute the team success. Lorge et al. (1958) described factors that contribute to team performance include motivation, situation or working environment, team interaction, type of tasks, and team size. The effect of all these factors is apparent because when a team member is not motivated or willing to accept a situation or a task, there may no final product or solution produced by that team.

It is recognized that every team member will have a different degree of task acceptance. The motivation factors reflect the individual's inspiration or desire to complete the task as a team. The motivation value is the value that the team members bring to their work, influenced by the amount of effort that they have put into it (West & Markiewicz, 2004). Lorge et al. (1958) provide the example of a team with five members. If two or more of the team members reject the task, the team can still produce something, but from the individual who rejects the task, there will be no outcome.

Additional factors that influence success in teamwork arise within the environment of the team itself and in the working environment. Creating an environment in which each team member is comfortable in taking reasonable risks in communicating, supporting positions, and taking action is important to ensure the team goals can be achieved. Team members need to have a positive attitudes, demonstrated by trust in and support for each other (Lencioni, 2002). The outside factors such as support received from others, for instance the project sponsors, help the team to succeed. Any other tools that can be provided by the project sponsors, such as new technology, may help smooth the design process.

How well team members interact with each other is another factor to determine the team success. There is no doubt that conflicts do exist in teams (Lencioni, 2002). The conflicts within a team are related whether to tasks, processes, or relationships (West, 2004). For example, one of the main purposes of working in team is to share knowledge and skills among the team members. Any unsolved arguments about the design process which relate to an individual’s knowledge and skills will potentially lead to the failure of the overall project. Stroebe and Diehl (1994) purport that the low number of potential solutions produced was due to lack of communication among the team members.

Research has informed us that there is a significant relationship between task complexity and team performance (Higgs, Plewnia, & Ploch, 2005; Lorge, et al., 1958). The level of difficulties or the complexity of a project influences the team performance. In the earlier section of creative process, Unsworth (2001) states the type of problems (open or close-ended) influence individual reactions in completing a task. It has been recognized that each individual person has a different level of knowledge, skill, and motivation. Therefore it has been suggested by Higgs et al.(2005) that it is necessary to determine the level of the project's complexity before assigning members to the team. The result could help determine the mix of individuals to be included in the team. A diverse team perhaps has a wider range of knowledge, skill, and experience, and therefore performs better in completing the task.

Finally, the number of team members affects the team's efficiency and productivity. Research has shown that the ideal number should be around five to eight persons in a team, depending on the type of problems assigned to the team (Lorge, et al., 1958). Depending on the type of problems, research has shown that small teams were more efficient with open or abstract problems, whereas larger teams perform better with closed and more directed problems (Lorge, et al., 1958).

Team Development

Research has shown that team development depends on four general stages or phases: forming, storming, norming, and performing. Bruce W. Tuckman proposed this model of group development in 1965. Tuckman's (1965) theory is based on work reviewing fifty articles that deal with stages of group development. The forming process involves the orientation, testing, and dependence constitute (Tuckman, 1965). At this stage, individuals within a team will seek information about other team members including their backgrounds and related experiences in the type of work assigned to them. Team members will ask questions about their roles and resources available to the team to complete the task. The most important task at this forming stage is to make sure that the team's goals and/or objectives are clearly identified and agreed.

In the next stage, storming, conflict and hidden tensions begin to emerge among individuals. Team members will start questioning the significance and achievability of the team task requirements. At this stage, the role of the team leader is to build a positive environment for his/her team members "to gain shared commitment to the team goals, to build trust, begin the definition of team roles, and to establish conflict resolution strategies for the team" (West, 2004, p. 29).

The phase after the conflicts are resolved is the norming stage. At this stage, team members begin to address the task positively and plans are made. Working approaches or 'norms' are established regardless of individual differences in the team.

Finally, in the performing stage, the team reacts to the plan. They start to see successful outcomes and their efforts focus productively on their joint task. Team members feel comfortable with each other and begin to work together more responsively.

West (2004), West and Markiewicz (2004), and Smith (2005) argue that team development is not a linear process but is a cyclic process. A team will go back and forth in their development process (Tuckman, 1965). Tuckman's (1965) model of small group development process has been accepted as a helpful starting point in discussing possible stages or phases of development of small working groups. It also must be recognized that not all teams fit into Tuckman's model of team development (Smith, 2005; Tuckman, 1965; West, 2004; West & Markiewicz, 2004).

Brainstorming

A brainstorming or collective ideation session is important in product development process. The idea of brainstorming originated with Alex F. Osborn in 1953 (Stroebe & Diehl, 1994). The brainstorming process is based on two principles which Osborn labeled as "deferment of judgment" and "quantity breeds quality" (Stroebe & Diehl, 1994). According to Stroebe and Diehl (1994) the principle of deferment of judgment involves a strict separation of idea generation and idea evaluation. This first principle involves either different people or two different team sessions for idea generation and idea evaluation. A strict application of the first principle should produce a high number of non-redundant ideas, and thus, higher quality ideas. Research has shown that these two basic principles enhance both the quantity of ideas produced, and the quality of the final product or solution (Stroebe & Diehl, 1994).

According to Stroebe and Diehl (1994) following these two principles Osborn derived four general rules of brainstorming: quantity is wanted, criticism is ruled out, "free-wheeling" is welcome, and combination and improvements are required. The first rule, quantity is wanted, enhanced team members' divergent thinking production. This rule aims to help problem solving over the maxim "quantity breeds quality". The assumption for this rule is that the more ideas generated, the greater the chance of producing a better solution. The second rule, criticism is ruled out, means any criticism of ideas generated should be avoided. Instead, team members should focus on extending or adding to the ideas, and reserve criticism for a 'critical stage' later in the design process. By keeping criticism on hold, team members will feel free to generate otherwise unthinkable ideas. The third rule is “free-wheeling” is welcome. This rule helps the team to voice a good number of unthinkable ideas. The unthinkable ideas can be generated by looking from new perspectives and again keeping on hold any critical assumptions about those ideas. These new ways of thinking will lead to finding better solutions. The final rule is combining and improving ideas. Multiple ideas that have been produced earlier may be combined to form a single better good idea.

Brainstorming has been recognized as a popular and widely used method of group interaction in both educational and business settings for developing creative solutions. In engineering education, especially in engineering design, teamwork is not a new approach in solving problems. According to Nguyen and Shanks (2009), “creative products are often the result of a collaborative teamwork” (p. 659). Other scholars in engineering design (e.g., Cross & Cross, 1995; Goldschmidt, 1995; Lewis, 2005b; Lumsdaine, et al., 1999) agree that teamwork benefits engineering students solving a design problem. The most difficult part in modern design is to develop teamwork skills among content experts who are working together on the design of specific product (Cross, 2008). Meanwhile, research shows that individual creativity helps teams produce creative products and solutions in dynamic research and development (R&D) processes (Pirola-Merlo & Mann, 2004). Despite the importance of teamwork in product design, the amount of research in related topics is considered small (Cross & Cross, 1995).

Teamwork in Engineering Design

There are expectations and assumptions related to team performance (Taggar, 2002). First, team outcomes may be influenced by team members' interaction. Second, the best solution should arise when team members utilize brainstorming, view the problem differently, redefine the problem, broaden information searches, and produce quality ideas. Finally, teams are expected to perform at the highest level when they have creative team members and effective team creativity-relevant processes.

Hill (1982) found that task differences, individual differences, and process differences have an influence on teams compared to individual performance. Miner (1984) supported Hill's argument that the "degree of process loss/gain and the relative performance of groups and individuals was significantly influenced by the dependent variable utilized and the decision making strategy employed" (p. 112). Like Miner (1984) and Hill (1982), in this study three independent variables: students' creativity, team interaction, and engineering knowledge -- will be examined on how they impact the engineering design product outcomes as the depended variable.

In addition, it has been commonly acknowledged that team performance is a positive function of a team ability (Yetton & Bottger, 1982). In terms of best team solution or outcome, Miner (1984) argues that whether teams are more cost-effective decision makers compared to individuals has yet to be proven. Yetton and Bottger (1982) claimed that individual versus team performance "is a paradigm with a long history in social psychology" (p. 308). Lorge et al. (1958) conducted an analysis on quality of group and individual performance based on a number of studies done over 37 years

(1920-1957). One of the Lorge et al.’s (1958) findings was that motivation factors could cause and influence the productivity of the group.

Engineering by its nature is a cooperative enterprise. Teamwork skills are more vital to the success of a project than technical expertise (Rugarcia, et al., 2000). However, Kemper and Sanders (2001) reported that in most cases, engineering schools did not pay much attention in preparing their graduates for working in team environments.

Engineering Design

Learning the process of engineering design is important for engineering students to help them understand the nature of developing a product or finding solutions to technical problems. Scholars in engineering design have defined engineering design as a systematic process of solving a technical problem for the benefit of society (Eder & Hosnedl, 2008; Eide, et al., 2002). A design is “a structured problem-solving activity” and a “process” is a phenomenon identified through step-by-step changes that guide us toward an expected result (Eide, et al., 2002). As described by Eder and Hosnedl (2008) “Designing in engineering has the purpose of creating the future operating artifacts, and the operational processes for which they can be used, to satisfy the needs of customers, stakeholders, and users” (p. 4). Lumsdaine et al. (1999) defines engineering design as “the communication of a set of rational decisions obtained with creative problem solving for accomplishing certain stated objectives within prescribed constraints” (p. 316).

The Accreditation Board for Engineering and Technology (ABET) has articulated the following definition of engineering design:

> Engineering design is a process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative, in which the

> basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet stated objectives. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include most of the following features: the development of student creativity, use of open-ended problems, formulation of design problem statements and specifications, considering of alternative solutions, feasibility considerations, production processes, concurrent engineering design, and detailed system descriptions. Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact. (Eide, et al., 2002, pp. 79-80)

According to Court (1998) the overall engineering design process core concept is to generate, evaluate, and use ideas. This means engineering designers should be able generate ideas and make use of them through the successful completion of a product.

The result of engineering design is often said to be the result of a problem solving process (Lumsdaine, et al., 1999). According to Rugarcia et al. (2000), some scholars identify creative thinking as one of the core skills that apply to problem solving, while others define problem solving as the primary skill, with creative thinking as a component. In engineering design, the engineers first must imagine more ways or options to solve the design problem. It is clear that in this first phase, engineers need to apply their creative thinking ability to a specific problem and come up with multiple ways or possibilities in solving the design problem. Typically, there is no one right answer for any design problem. However, at the end, the engineers have to choose and make a decision from a wide range of possibilities to create the design solution that satisfies customer needs. This decision includes, but is not limited, to choices of shape, size, color, type of material, manufacturing process, and so on to fulfill the final design specification.

Engineering Design Variables

Some would believe that everyone has the capability to create or design a product or solution based on his or her knowledge and experiences. Knowledge of the subject matter, for example engineering knowledge, will lead a person to the systematic process, which uses the engineering method or principles to solve the problem.

Design is essential in the engineering field because it is the thing that engineers do (Eide, et al., 2002) . Kosky et al. (2006) have argued that one of the biggest challenges of engineering design is the level and amount of knowledge required of the designer. Haik suggests that "engineering design is the creative process" (Haik, 2003, p. 3) of identifying needs and then devising a solution to fill those needs. Other scholars have expressed similar ideas (e.g., Court, 1998; Eder & Hosnedl, 2008; Eide, et al., 2002; Vzyatishev, 1991). To accomplish the design goal of creating new products or solutions, engineering design uses combinations of available technologies to improve performance, lower cost, and reduce risk (Kosky, et al., 2006).

Engineering Design Process (EDP) steps can be described from the main steps to the most specific and detailed process. Each step involves a special task or strategy to meet the goal of the task. The "design process is iterative in nature" (Eide, et al., 2002, p. 81). For example, some would believe that how quickly you create an initial product prototype is relative to how successful the end product will be. In other words, the earlier you invite feedback on the product, the more chances you have to revise and improve it. As the solution to a design problem develops, the engineering designer will be continually refining the design. While implementing the solution to a design problem, the engineering designer may discover that the solution developed is unsafe or beyond the budget. He or she must then goes back to the drawing board, sketchbook, or computer and modify the solution until it meets the design requirements.

Cross (2008) described the design methods as procedures, techniques, aids, or tools used in design. The design methods represent a number of distinct kinds of activities that the engineering designers might use and combine into an overall design process. Up to recent years, many design projects were too complex to be resolved satisfactory by the conventional method. Therefore, the main reason behind the development of new methods is to bring rational procedures into the design process. As an engineering student, the goal is to obtain the essential knowledge and experience needed to understand the design process and become involved in meaningful design activities (Eide, et al., 2002).

Time is another variable that has been considered as one of the most important in design activity (Eide, et al., 2002). Therefore, project planning or scheduling is crucial in engineering design process. Even though engineers have the knowledge and experience to work with their project/problem, they also need to plan and use a systematic approach to meet the goal. The development of a new product according to the design process is always limited by the time available for the entire process; many projects have failed due to lack of attention to planning (Haik, 2003). The most popular scheduling approach used in project management is the Gantt chart introduced by Henry L. Gantt and Frederick Taylor in early 1900s (Haik, 2003). Each detailed task necessary to complete the project should be listed with the time period to complete. This helps the design teams to stay on track and helps them to trace what they may have missed in completing the project. According to Kosky et al. (2006) “the main goal of the systematic approach to engineering design is to eliminate personal bias from the process and to maximize the amount of thinking and information gathering that is done up front, before committing to the final design" (p. 312).

Time has a significant relationship to cost in the design process (Haik, 2003). Within the industry, design is a risk and there is no design project without cost. The cost involved in the design project includes labor, materials, technology, manufacturing process, and so on. Therefore, both time and cost are critical because design projects usually consume significant human resources and may extend several years. Detailed planning in such projects produces a better design product and eliminates or reduces the costly overruns and missed deadlines.

Engineering Design Process (EDP)

In solving an engineering design problem, engineers have a tendency to conduct preliminary investigations and then propose a range of possible solutions until they find one that is acceptable and suitable (Cross, 2008). When they are designing, engineers therefore, rely on a range of approaches based on "taking an idea, modifying it to increase its certainty and providing specific details for manufacturing" (Court, 1998, p. 143). Design methods "represent a number of distinct kinds of activities that the designer might use and combine into the overall design process" (Cross, 2008, p. 46). There are a number of engineering design process (EDP) models being published. The simple EDP described by Khandani (2005) involves five main tasks. It begins with defining the problem, gathering the pertinent information, generating multiple solutions, analyzing and selecting a solution, and testing and implementing the solution. The specific tasks of

EDP described by Lumsdaine et al. (1999) involve twelve tasks including: (a) identify forces driving design, (b) identify constraints, (c) identify user needs, (d) identify design specifications, (e) analyze problem and context, (f) plan design process, (g) develop concepts/best options, (h) determine parametric/system level design, (i) determine tolerance level design, (j) production design test, (k) evaluate/review design, and (l) communicate the results.

In the first task, identifying forces driving the design, Lumsdine et al. (1999) described how important it is for engineering designers to gather as much information about the product as possible, including information from the customer, the stakeholder or sponsor, the technology opportunities, and so on. Next, the engineering designers need to identify any constraints that are imposed by the stakeholder or sponsor of the project. The major concern among the stakeholders or project sponsors may be the cost of completing the project. This constraint definitely will limit the design project. The next task is to determine the end user needs. The goal of this task is to produce a list of the preferred or favorite features of a design product and then weight them according to user preferences. Once the customer needs have been identified, the engineering designers have to translate these expressions into the design specifications. These first four tasks provide most of the information needed before engineering designers proceed to the conceptual design phase.

In the conceptual design phase, the engineering designers need to develop an effective design problem analysis statement, since the information gathered before is typically not organized into a concise statement of the design project. The design problem analysis statement can help as an evolving master guide for everyone in the design team.

Once the design problem is finalized, the next step is to plan the design project. In this task, each specific job for the project needs to be listed. Detailed planning helps produce a better product and avoid overrun costs and missed deadlines. The detailed project approach and planning statements then need to be reviewed and approved by the stakeholders or the project sponsors.

When the project approach and plan have been reviewed and approved by the stakeholders or the project sponsors, the engineering designers may proceed to develop several design concepts before they select the best alternative that meets the requirements. Selecting the design concept is the first and most significant decision in the design process. Next, the engineering designers need to identify the design parameter including the materials, sizes/dimensions, capacities, components, assembly, purchased components, etc. Once the design parameters have been identified, the next task is to determine the complete detail or tolerance of the design for production. In most cases, all parts of the design require testing to validate the decisions, especially when the designed product depends on new technology or the use of current technology in new ways. Constructing a test model or prototype is the most favorable way to accomplish this task. The tests on the prototype help to validate the entire design process.

Once the design and the production process have been tested, the engineering designers need to review and evaluate the entire design process. The review and evaluation of the design process provides necessary information including the testing procedure and results as well as the recommendations for design changes (if needed). Finally, once the entire design process has been reviewed and evaluated, the engineering designers have to refine, improve, and communicate the results for each stage of the design process, especially to the stakeholders or project sponsors.

Eide et al. (2002) suggest ten tasks involved in EDP. Table 2.5 shows the EDP phases by Eide et al. (2002) and tasks with their descriptions to elaborate each phase.

Table 2.5

Engineering Design Process (EDP) (Eide, et al., 2002)

	Phase	Task	Description
1	Elaborating the assigned problem	Identification of a need	• Market survey to understand the market need.
		Problem definition	• Set the design goals. • Specified function, technical requirements, and costs.
		Research	• Gather the relevant information such as product history. • Brainstorming.
2	Conceptualizing the design	Constraints	• Design for production. • Identify the appropriate manufacturing process. • Cost, time, and resources selection.
		Criteria	• Defining the specifications for the design • Prototype. • Detailing the design.
3	Laying out the design	Alternative solutions	• Identify the overall product function structure. • Generate multiple solutions or alternative concepts. • Sketches.
		Analysis	• Compare the specified and actual functions. • Analyze and select the solution or concepts. • Establishing the design requirements. • Testing. • Numerical approach.
		Decision	• Accepting or rejecting the product. • Redesign
4	Detailing the design	Specification	• Production drawings. • Selecting the production processes. • System or process integration.
		Communication	• Preparing the final design report. • Oral presentation.

The four phases of the EDP are described by Eide et al. (2002) include:

Phase 1. A very important phase during the design process is to elaborate the assigned problem. This is critical because it includes three very important tasks. The first task is the identification of a need. Understanding the “need” may sound vague, but it is the mode that generally begins the process. “When most of us speak of a need, we generally refer to the lack or shortage of something we consider essential or highly desirable. Obviously this is an extremely relative thing, for what may be necessity to some could be a luxury to others” (p. 86). Once the identification of need is completed, the next step in solving the engineering design problem is to define the problem itself. Before engineering designers think about solutions, they need to be sure that the problem is well defined. At this stage, engineering designers should not point or identify any specific solution thus leaving the opportunity to consider a wide range of alternatives before they agree on a specific problem statement. In other words start with “broad definition first” (p. 88). Once the problem is defined, the research phase begins. The problem itself generally guides what types of information or data are to be gathered. “The search for information may reveal facts about the situation that result in redefinition of the problem” (p. 90). At this stage, “no formal list of possible solutions has been developed” (p. 80). There are several sources that can be used to gather the information such as existing solutions, the Internet, libraries, government documents, professional organizations, trade journals, vendor catalogs, and individual experts in the field. These three elements help to focus elaboration on the assigned problem which is generally considered as phase one.

Phase 2. In phase two there are two important tasks. The first is identifying the constraints. Constraints mean "physical and practical limitations that will reduce the number of solutions for any problem" (p. 94). In engineering design, the constraints are considered "boundary conditions". Constraints in engineering design include cost, time, and resources available and needed to solve the problem. Once the team has identified the design constraints, they need to identify the design criteria which are described as task 5. "Criteria are desirable characteristics of the solution which are established from experience, research, market studies, and customer preferences. In most instances the criteria are used to judge alternative solutions on a qualitative basis" (p. 95). Eide et al. (2002) further described additional elements that engineering designers must consider in the design process. Eide et al. (2000) described elements like cost, reliability, weight, ease of operation and maintenance, appearance, compatibility, safety features, noise level, effectiveness, durability, feasibility, and acceptance. The engineering designer must consider these additional concerns during task five of the process in which understanding of the design criteria is sought. For example, cost could be either a constraint that limited the design process or it could be a marketing criteria. These are examples of how the engineering designer must consider not only design process criteria but also the criteria that impact and affect the design. In selecting the design criteria, Eide et al. (2002) suggest engineering designers ask themselves what type of criteria are most desirable and which are not applicable. Perhaps not all of these twelve criteria are important in a given design project, but the engineering designers have to decide which criteria are important to the overall design. These two tasks in the second phase help the design team to conceptualize the overall design before they can lay it down to alternate solutions.

Phase 3. There are three main tasks in this phase including the alternative solutions, analysis of the potential solution, and making a decision on which solution meets the design criteria as well as its constraints. This is where the members in a design team tend to identify the overall product function structure, start to brainstorm, generate multiple solutions, and sketch. This is also done within constraints. Two effective methods to compare and select the best alternative solution with the chosen criteria that have been discussed by Eide et al. (2002) are “Checkoff lists” and “Brainstorming”. “Checkoff lists … suggest possible ways an existing solution to your problem might be changed and used” (p. 98). Brainstorming is a session of productive discussion among a group of people (4-8 people) to generate ideas, often without judging their merit. The next task is analysis. At this stage, the design team has an established well-defined problem. To find the best alternative solution, “the potential solutions which are not proved at this stage may be discarded or, under certain conditions, retained with redefinition of the problem and change in constraints or criteria … Analysis involves the use of mathematical and engineering principles to determine the performance of a solution” (p. 102). At the end of this phase, the design team has to decide on a best solution. Decision-making is a very difficult task, especially when dealing with “trade-offs”. The term “optimization” is used to emphasize that the designers should seek the best, or optimum, value in light of criteria. Numerical and modeling methods are the most powerful tools for optimization.

Phase 4. This is the final phase in the design process. In this phase, the design team is required to come up with the design specification. This task involves preparing documentation on the selected design solution for manufacturing. The specification for the selected design is presented as technical drawings and a technical written document. Finally, the design team is expected to communicate their findings. The purpose of this task is to convey to the customer or others the final design. The communication could be in a written document (report) and/or oral presentation.

Engineering design has both creative and rational elements (Lewis, 2005b). There may be differences in EDP models, but "there is a need to improve on traditional ways of working in design" (Cross, 2008, p. 45) due to the complexity, high risks and costs of design in the 21st century (e.g., new materials, new machines, etc.). Furthermore, Cross (2008) stated, "There is more general concern with trying to improve the efficiency of the design process" (p. 46).

Lewis (2005a) believes "the design process is not linear" (p. 37) and there will be no single best solution in engineering design. These engineering design steps are useful for engineers as guidelines and principles in developing new products or solutions. Engineers believe there is no single "correct" solution for their final product. Most of the time, designers have to "search for the best possible design under severe conditions of limited time and limited resources (especially cost)" (Kosky, et al., 2006, p. 310). Therefore engineers need to be creative to generate new ideas toward the best solution for implementation/application.

Creativity, Knowledge and Teamwork in Engineering Design

In most cases, employers automatically assume their engineers are creative and that is one criteria by which they are hired (Kemper & Sanders, 2001). Engineers not only need to have content knowledge but also need to be creative in solving an engineering design problem. As described in the EDP section, engineers need to apply creative thinking, especially at the beginning stages of the design process and while identifying the design problem. As described by Stouffer, Russell, and Oliva (2004),

> the creative process must go through a series of four stages, beginning with 1) a notion or need (sensing, problem definition, and orientation); 2) an investigation of that notion or need (testing, preparation, incubation, analysis, and ideation); 3) an articulation of a new idea or solution (modifying, illumination, and synthesis); and 4) a validation process of that idea or solution resulting in an idea, theory, process, or physical product (communicating, verification, and evaluation). (p. 2)

In reflection, the creative process is not much different from the EDP discussed above. This indicates that a relationship between EDP and the creative process can be made. Most engineering design textbooks acknowledge that creativity is an essential skill in EDP. Like EDP, creativity is not necessarily sequential “as many avenues are explored and many refinements occur before a solution is arrived at” (McKeag, n.d., p. 5).

As most engineers in practice work in groups, the need to integrate their knowledge and experiences is crucial to produce a better solution or product. At the same time, assessment of design and problem-solving activities in engineering and technology education is still a fledgling area because the field has not defined measures for determining the degree of creativity shown in students’ designed-related work (Lewis, 2005b).

Lumsdaine et al. (1999) listed 18 desirable individual traits that make up a creative team (see Table 6). Note that not all team members will have all of these traits, but a creative team would exhibit many of these traits.

Table 2.6

What makes a creative team?

What Makes a Creative Team?

- Intelligence: high intellectual standards.
- Expertise in problem area or related fields.
- Variety of experiences outside the problem area; broad interests; multidisciplinary.
- Willingness to test assumptions.
- Self-discipline; strong work ethics; commitment.
- Perseverance and concentration.
- Skill for dialogue and candid debate with customers and coworkers.
- Enthusiasm and energy.
- Openness to new ideas; eagerness to learn.
- Ability to toy with ideas; originality; tinkering.
- Tolerance for ambiguity; flexibility.
- Willingness to take risk; no fear of making mistakes.
- Ability to defer judgment.
- Curiosity, inquisitiveness; imagination; creativity, resourcefulness; vision.
- Humor and impulsiveness.
- Willingness to consider multiple approaches and look for the "unobvious".

Note. Adapted from "Creative problem solving and engineering design" by Edward Lumsdaine, Monika Lumsdaine, and J. William Shelnutt, 1999, p. 96.

Lumsdaine et al. (1999) presented what makes a creative team in their argument represented in Table 2.6. It is interesting to know that many of the characteristics within the four dimensions presented by Cropley (2000) shown previously in Table 2.4 emerged. For example, "openness to new ideas" and "eagerness to learn" are in consonance with Cropley's (2000) "flexibility" and "acceptance of own potential differences". Another one of Lumsdaine elements of "enthusiasm and energy" strikes similarity to Cropley's motivation dimension, which included "desire to go beyond the conventional". Therefore, it appears that the team characteristics and creativity characteristics resonate in the literature with regard to what elements are shared by a creative team.

Lumsdaine et al. (1999) also argued that there is no genetic factor in becoming an effective team member. To be an effective team member, one should have selfawareness, attention, and a hard-working attitude to develop and enhance the skills required. Team members need to recognize that there are skills to be learned before they can become effective in a team. Lumsdaine provides an example that a team member who can communicate with ease with others may have learned and practiced to be an active listener for months or maybe years.

Summary

Wright (2002) believes that engineering can be viewed as an art and a science. However, in terms of creativity, engineering creativity is different from creativity in fine arts and other fields (Cropley & Cropley, 2005). Engineering creativity can clearly be seen through the outcome, the product, device, or system being developed by engineers (Cropley & Cropley, 2005). Engineering creative products or outcomes are often described as having the three primary characteristics of novelty, value, and surprisingness (Nguyen & Shanks, 2009). Cropley and Cropley (2005) go into more detail about the characteristics of creativity in engineering.

Although numerous studies on creativity have been, Treffinger (1986) argues that there exists no theory of creativity and he believes that there will never be a general theory of creativity. However, Treffinger acknowledges research on creativity contributions in the past has allowed and helped future researchers to be more systematic in understanding, describing, and categorizing creativity and its definitions. Any scientific research has forced researchers to introduce ideas and concepts in studying creativity (Bellman, 1964).

Engineering by its nature is a cooperative enterprise. In engineering education, although creativity and teamwork could be enhanced and probably understood by both instructors and students, problems in understanding the creative and teamwork processes still exist (Kemper & Sanders, 2001; LaChapelle, 1983). At the same time, it has been recognized that knowledge and experience are not enough to become an engineer. Hands-on skills dealing with the systematic approach of engineering design is becoming an imperative and is considered the best way for engineering students to be exposed to the design process. In engineering design, creativity and ability to work in a team environment can be measured by assessing the choices being made in reaching original solution to a problem, for example, to what extent the choice made is successful in solving the problem and to what extent it is unusual (Alger & Hays, 1964; Rugarcia, et al., 2000).

Design under constraint is an important concept. Engineering designers deal with a number of limitations in completing projects. Time, cost, and resources are the main factors to be considered to successfully complete an engineering design project. As stated in the Standards for Technological Literacy: Content for the study of technology (STL; ITEA, 2007)

> The modern engineering profession has a number of well-developed methods for discovering such a solution, all of which share common traits. First, the designers set out to meet certain design criteria, in essence, what is the design supposed to do. Second, the designers must work under certain constraints, such as time, money, and resources. Finally the procedures or steps of the design process are iterative and can be performed in different sequences, depending upon the details of the design problem. (p. 90)

For example, Khandani’s (2005) design criteria should be considered in designing a mouse trap: (a) low cost, (b) safe, particularly with small children, (c) not be detrimental to the environment, (d) be aesthetically pleasing, (e) be simple to operate, with minimum human effort, (f) must be disposable (you don't reuse the trap), (g) not cause undue pain and suffering for the mouse. According to Eide et al. (2002), “the best way to develop a capability to perform engineering design is to go through the design process and to arrive at a solution to a real problem” (p. 87). Eide et al. (2002) suggest “The objectives of all entire design process is to choose the best solution for a problem within the time allowed” (p. 108).

An understanding of the engineering design process is important both to manage the design activity to aid the improvement of products or solutions, as well as to determine the overall efficiency of the engineering industries. It has been argued that creativity is important and crucial in the engineering design process and without it, there would be no innovation and commercial value (Amabile, 1996; Mumford & Gustafson, 1988; Thompson & Lordan, 1999). Within the engineering industry, creativity does not essentially associate to success. However, without creativity, based on the previous research, long-term failure is probable (Howard, Culley, & Dekoninck, 2008).

For a company to be sustainable and competitive, it is crucial that its products are sold successfully, that it remains in the market, and that it takes advantage of market change by refining the products. In general, creative thinking is considered an important skill in design. According to Lewis (2005b), “the need for focus upon creativity in engineering and technology education has been made more urgent than before because of the prominence given to the teaching and learning of design” (p. 35). The International Technology Education Association (ITEA, 2007) has addressed twenty STL standards and four of them (Standards 8, 9, 10, and 11) are directly focused on engineering design.

However, it is difficult to find literature and empirical studies that discuss specifically and extensively the application of creative thinking to the engineering design process.

CHAPTER 3: METHOD

"You can measure anything"- Douglas W. Hubbart (2007)

Overview of the Chapter

In this chapter an overview of the research procedures and methods used in this study including the research design, sampling strategy, instrumentations, data collection strategies, data analysis, and limitations are presented. Figure 3.1 illustrates the relationships among engineering knowledge, creativity, and team interaction and the impact on senior design outcomes in the study. The main purpose of this study was to determine whether creativity, engineering knowledge, and team interaction are related and their impact on the outcomes in senior design projects.

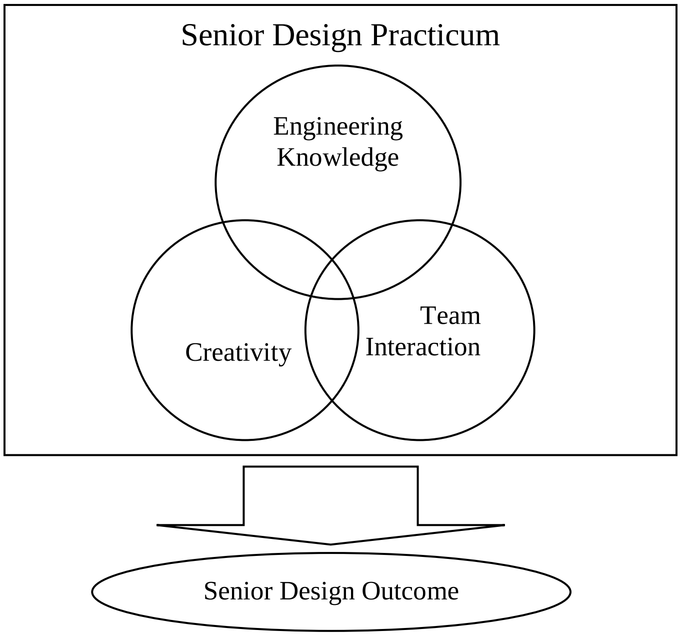


Figure 3.1. The relationships among creativity, engineering knowledge, and team interaction and the impact on outcome in senior design projects

Research Design

Because “social phenomena are almost always complex” (Miller & Salkind, 2002, p. 19) to study, choosing an appropriate research design for any social science research project is the biggest concern of any researcher (Berliner, 2002). The appropriate research design helps those who seek to examine the validity of hypotheses as well as how best to indicate either to accept or reject them (Miller & Salkind, 2002).

A quantitative approach is used in this study. The design of the study is associational or also known as correlational research. According to Creswell (2005) and Isaac and Michael (1995), a correlational research design is useful to describe and explain the relationship among variables. Correlational design also provides an opportunity for researchers to determine the patterns of two or more variables that could be used to predict scores or an outcome (Creswell, 2005; Isaac & Michael, 1995).

One nonrandomized group of participants was measured on three factors including creativity, engineering knowledge, and team interaction. Each participant’s composite engineering course grade point average (GPA) was used as a proxy to represents his or her engineering knowledge. To use this approach, the researcher obtained the grades from each of the student’s engineering courses that were required before they could enroll in the senior design practicum – MECH486A. For the second variable, the TTCT (Figural Form A) was used to measure the four constructs of students’ creativity; fluency, flexibility, originality, and elaboration. The Team Climate Inventory (TCI) questionnaire measures the four dimensions of vision, participation safety, task orientation, and support for innovation as the team interaction pattern. The senior design outcome score represents student team achievement in developing a new product or engineering solution by using an independent Judging Criteria rubric adapted from the Student Product Assessment Form (SPAF), developed by Sally M. Reis (Reis, 1981) to measure the team design outcome.

Reflection on the Study Limits

The findings in this study are contradicted by the literature due to the following reasons:

Small sample size (n=12 teams). One limitation of this study is the small sample size. It has been agreed among statisticians in the social sciences that a larger sample size will provide a better chance that the scores will be normally distributed to represent the population of the study. The maximum sample size for this study was 99 participants. However, since this study used voluntary participants, the number has been reduced to 55 (n = 55). In the 2011/2012 academic year mechanical engineering senior design capstone course, there were 22 projects involved. Although there were 99 students who enrolled in that class in fall 2011, they were assigned to these 22 projects. The team size is unequal and ranged from two to eight students per team. Although in this study there was no statistical difference found between design teams and since there were 12 design team volunteers to participate, this unequal team size affects the composite score used to represent each team's creativity. This number affects the findings, because the data may not represent the population of the study. In addition, if the researcher decides to make inferences to a larger population which is beyond this study, sample size does matter (Creswell, 2005; Gliner, Morgan, & Leech, 2009).

Time period of data collection. The TTCT test was administered in early fall 2011 (week 3), while the senior design outcome was scored/evaluated at the end of spring 2012 (week 26). A 23 week difference between TTCT and the senior design outcome score could affect the results of the study. Participants' maturity effect while they are solving the engineering design problem has potential to influence the results.

Measurements. There were a few measurement issues that might influence the findings. The first issue related to the possibility that the engineering GPA may not be an appropriate measure to represent student level of knowledge due to reasons that will be discussed in Chapter 5. Second, the researcher did not conduct a reliability analysis on the TTCT due to limited information on the evaluation process received from Scholastic Testing Service (STS). This included the number of raters who evaluated the test and TTCT score from each rater. This information would be helpful for the researcher to examine the interrater reliability of the TTCT in this study. The third issue was related to the senior design judging criteria rubric. The adapted judging criteria rubric had interrater reliability ranging from .55 to .68 which maybe not sufficient. The undetermined TTCT reliability and low judging criteria reliability may influence the results in this study.

Research design. Correlational research design has played a major role in educational research especially in exploring the relationships between factors that contribute to student success. While correlational methodologies can be used to examine a relationship between two variables, the interpretation of the results needs to be done with caution. Correlations or relationships among variables cannot prove that one variable causes a change in another variable (Gliner, et al., 2009). Correlation does not indicate cause and effect, or causation. For example, if there is a significant relationship between engineering knowledge and creativity, the correlations do not show that engineering knowledge increases or decreases the engineering student's creativity. Another limitation is that correlational research commonly suggests that the variables are linearly related to one another and when the linearity assumption is violated, correlational methods reduce the strength of the relationship.

Permission and Approval

Institutional Review Board (IRB) of Colorado State University approval was obtained before the study was conducted (Appendix B). In addition, since the study involved classroom and lab activities, the cooperation of the course Professor was necessary. The permission to use and/or to revise the instruments in this study was secured from the original authors, including the authors and/or copyright owners of the TTCT, the TCI, and the SPAF.

Research Context: Engineering design practicum

One of the requirements in most baccalaureate engineering programs is to have an engineering design practicum or final project. The Accreditation Board for Engineering and Technology (ABET) requires that the mechanical engineering curriculum be designed to:

> Require students to apply principles of engineering, basic science, and mathematics (including multivariate calculus and differential equations); to model, analyze, design, and realize physical systems, components or processes; and prepare students to work professionally in both thermal and mechanical systems areas (Acceditation Board of Engineering and Technology Education, 2011, p. 16).

The engineering design practicum generally is designed to provide engineering students exposure to a real and practical problem involved in the real world, as they will become engineers in the near future. At Colorado State University (CSU), the Mechanical Engineering Design Practicum is a one-year course split into two semesters (MECH486A in the fall semester and MECH486B in the spring semester), and students must complete both semesters and earn at least a grade C to complete the program/degree.

The CSU Mechanical Engineering bachelor's degree program has been designed to meet the objectives and outcomes as shown in Table 3.1.

Table 3.1

The CSU Mechanical Engineering Bachelor's Degree Program Objectives

CSU Mechanical Engineering Bachelor's Degree Program Objectives	
a) ability to apply knowledge of mathematics, science and engineering. b) ability to identify, formulate, and solve engineering problems. c) ability to design and conduct experiments, as well as analyze and interpret data. d) ability to design a system, component or process to meet desired needs within realistic constraints. e) ability to function on multi-disciplinary teams.	f) ability to use techniques, skills and modern engineering tools necessary for engineering practice. g) ability to communicate effectively. h) understanding of professional and ethical responsibility. i) understanding the impact of engineering solutions in a global, economic, environmental, and societal context. j) knowledge of contemporary issues. k) recognition of the need for lifelong learning.

Note. Retrieved April 15, 2011, from http://www.engr.colostate.edu/me/pages/objectives_outcomes.html

Table 3.1 shows that the Department of Mechanical Engineering has designed the program to meet their objectives. The objectives have general areas of engineering science and knowledge, engineering design, and experimentation. It also has engineering practice elements including working in multidisciplinary teams, communicating effectively, being professional and responsible, and areas of global concern like being able to look at global solutions, economic solutions, understanding the role of engineering in contemporary society, and being a life-long learner.

In addition to the objectives and outcomes shown in Table 3.1, the Department of Mechanical Engineering is concerned with the professional practice of their graduates (Department of Mechanical Engineering Colorado State University, 2011a). Therefore, Table 3.2 shows the expected impact of their education on their professional practice.

Table 3.2

The CSU Mechanical Engineering Bachelor's Degree Program Expectations

CSU Engineering Bachelor Science graduates expectation	
a) Identify, analyze, formulate, and solve engineering problems associated with their professional position, both independently and in a team environment; b) Manage multi-faceted and multi-disciplinary projects with significant legal, ethical, regulatory, social, environmental, and economic considerations using a broad systems perspective;	c) Communicate effectively with colleagues, professional clients, and the public; and d) Demonstrate commitment and progress in lifelong learning, professional development, and leadership.

Note. Retrevied April 15, 2011, from http://www.engr.colostate.edu/me/pages/objectives_outcomes.html

The professional practice component states that within a few years, students will be able, for example, to begin to engage in engineering problem solving, both in an independent and team environment. Bachelor graduates must understand the multidisciplinary nature of engineering that includes significant issues around legal, regulatory, social, and economic considerations. Further, the department hopes that graduates are committed to clear communication not only with their peers but also among professional clients and the public. Also, they are expected to demonstrate their commitment to lifelong learning and leadership.

The actual curriculum experienced by the students is designed or targeted to have engineering skills as shown in Table 3.1 and broad professional development skills as shown in Table 3.2. The actual curriculum and its phases that the students are engaged in are shown in Figure 3.2.

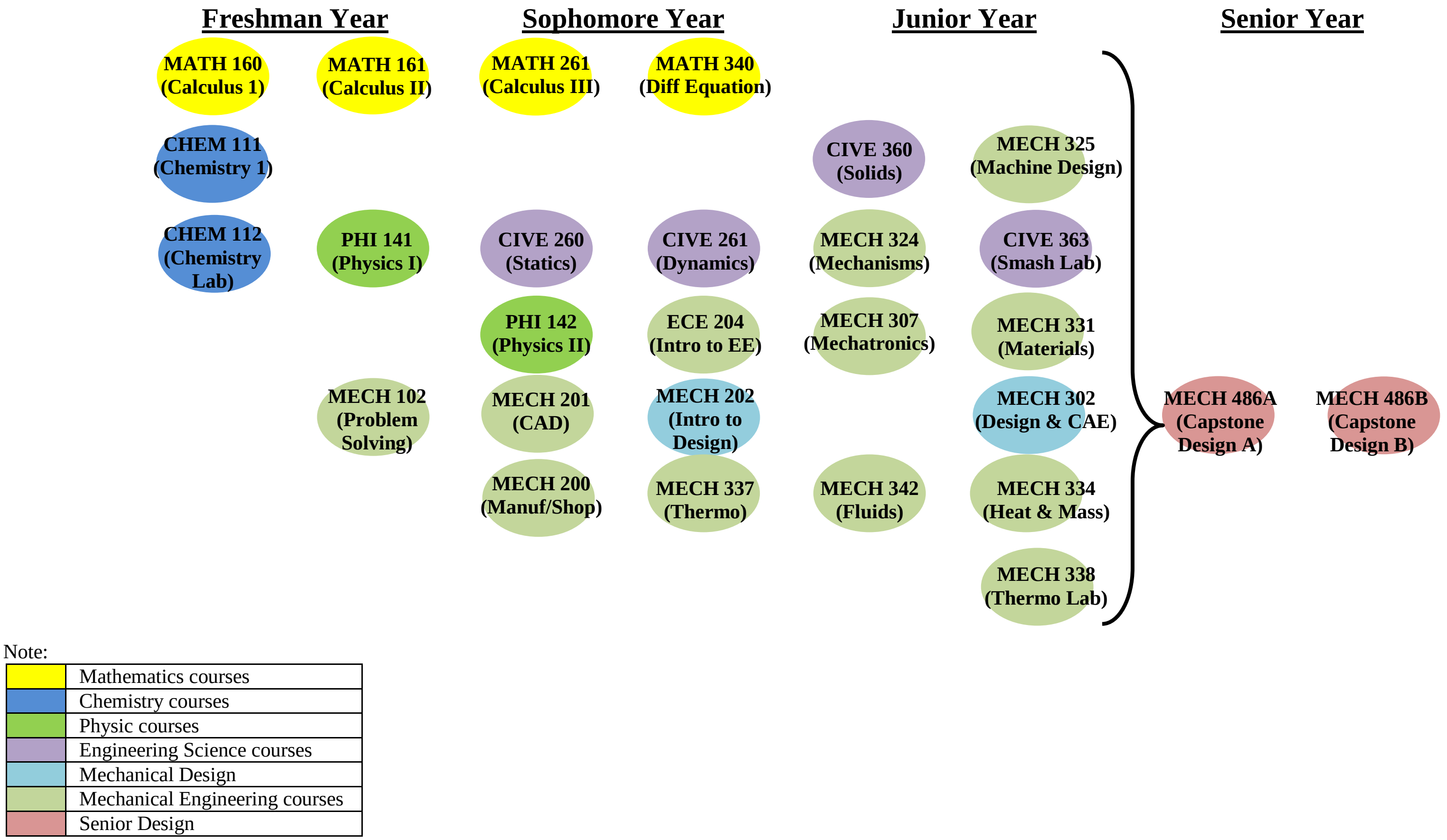


Figure 3.2. Senior design practicum prerequisite courses (Adapted from Department of Mechanical Engineering Undergraduate Curriculum Guide Fall 2011, Retrieved March 11, 2011, from http://www.engr.colostate.edu/me/pages/documents/ UndergradCurricGuideFall11.pdf

Figure 3.2 shows the learning progression for CSU mechanical engineering undergraduate students (Department of Mechanical Engineering Colorado State University, 2011b). During the first year, students generally concentrated on mathematics, chemistry, physics foundations, and the mechanical engineering profession and practice are introduced. In the second year, students continue with mathematics and began engineering science including statics, dynamics, mechanics, thermodynamics, and introductory design courses. In the third year, engineering analysis and laboratory classes in mechatronics, mechanisms, thermal/fluids, heat and mass, and mechanics need to be completed.

During the final year, students have a year long capstone design course. In this capstone design course, students must work in teams designing engineering projects. The goals of the Mechanical Engineering Design Practicum are to:

> 1. apply concurrent engineering principles to a competition project in a team environment;
> 2. follow a significant and complex mechanical engineering design project from initial specification through conceptual design, detailed design, manufacture, test, and application; and
> 3. individually specialize and apply knowledge to various mechanical engineering disciplines. (Department of Mechanical Engineering Colorado State University, 2011c, p. para. 4)

The practicum is designed to prepare engineering undergraduate students to be effective in their future profession. The course helps students learn how to take advantage of their work by maximizing the input of effort. Each group has 26 academic weeks to complete their project. In the Mechanical Engineering Design Practicum (MECH486A and B), students meet on a weekly basis for a one hour lecture and four to five hours of lab work where each team discusses and works on their specific design problem.

Participants and Sampling Procedures

Students enrolled in MECH486A in fall 2011 were selected as participants in this study. There were two groups of students, including the Mechanical Engineering and Engineering Science students, involved in this study. Students were expected to have sufficient knowledge in both engineering and engineering design based on the prerequisite courses taken.

Ninety-nine students were enrolled in engineering design practicum in fall 2011 ($N = 99$). At the beginning of the fall semester, the Professor asked his students for their résumés, including details about their academic profile (e.g., major, current overall grade point average (GPA), etc.), interests, experience, and the four top choices of the engineering design project assignment. The résumés helped the Professor and his committee including the co-instructor and graduate teaching assistant to assign students to teams working with specific engineering design problems. Students were assigned to teams based on their profiles and project choice and were not given the option of choosing their group members.

The sampling strategy for this study was a purposive sampling technique. Appendix A shows the list of engineering design projects involved in this course. According to the course Professor, 95% of students received either their first or second choice of project. Team sizes were uneven. The minimum number for a design team was two students (one team) and the largest was eight (one team). One project was being completed by an interdisciplinary team including students from Mechanical Engineering, Electrical Engineering, Chemical Engineering, and two students from Biomedical Engineering that were not considered as the population in this study. One other project was being completed by a pair of students. Out of 22 design teams, there were 12 design teams of 55 students who volunteered and participated in this study.

Site Selection Description

The study was conducted in the Mechanical Engineering Department at Colorado State University (CSU). The MECH486A/B course was selected for the purpose of the study. Convenience was the main factor in selecting CSU as the site for the study. The researcher completed his doctoral study at the same university.

Demographic Questionnaire

At the beginning of MECH486A, students were asked to complete the background data questionnaire (Appendix C), which asked their major, current overall GPA, interests, and experiences in engineering design. The participants background questionnaire helped to form a team profile including the average team engineering knowledge, team interests, and team experiences in engineering design.

The students signed the “Student Permission to Release Academic Record” (Appendix D) giving permission to the researcher to access their academic records. As a measurement of participants engineering knowledge, the researcher manually calculated engineering courses’ GPA based on the prerequisite courses shown in Figure 3.2.

Measures and Specifications

For the purpose of this study, only the instruments related to each construct and used in the study are discussed in this section. The data were collected using the four instruments: (a) demographic questionnaire, (b) team interaction questionnaire, (c) engineering courses' GPA, and (d) creativity tests. The adapted SPAF were used to represent the team outcome score.

Engineering Knowledge Score

It has become common in mechanical engineering programs to have students complete required courses in their major before they can enroll in the senior design project course. For the purpose of the study, the researcher used individual engineering course grades as a proxy to represent student's engineering knowledge. Engineering course GPA is the mean grades of all required engineering courses taken including all courses in physics, chemistry, mathematics, engineering science, and mechanical engineering. A course has a grade and quality points ranged from 0 to 4.00. A GPA is a result from the calculation of quality points from the included courses. The researcher manually calculated each student's engineering course GPA using Microsoft Excel 2010 and transferred the results into IBM Statistical Package for the Social Sciences (SPSS) version 20 software for further analysis.

Team Climate Inventory (TCI) Questionnaire

The adapted TCI was used to assess the team climate with regard to team improvement and performance (Anderson & West, 1998; Loo & Loewen, 2002; Vona, 1996; West, 1990; West & Anderson, 1996). Unlike other tools that measure team climate, the TCI focuses on the team instead of the individual team members (Vona, 1996). Currently there are two versions of the TCI: the short version which consists of 38 items (used here) and the long version which consists of 61 items. Both versions measure four constructs: (a) vision, (b) participative safety, (c) task orientation, and (d) support for innovation. Vision has been defined as an idea of a valued outcome that could motivate the team at work. The team will be more effective if they have a clear and focused vision (Vona, 1996). Participative safety "relates to active involvement in group interactions wherein the predominant interpersonal atmosphere is one of non-threatening trust and support" (Anderson & West, 1998, p. 240). Task orientation "describes a general commitment to excellence in task performance coupled with a climate which supports the adoption of improvements to established policies, procedures, and methods" (Anderson & West, 1998, p. 240). Finally, support for innovation has been defined by West as "the expectation, approval and practical support of attempts to introduce new and improved ways of doing things in the work environment" (Anderson & West, 1998, p. 240). The TCI was reported to be highly reliable, the Cronbach alphas ranging from .84 to .94 (Loo & Loewen, 2002). Permission to use and adapt the questionnaire was granted by Michael A. West from Aston University, Birmingham, UK (refer to Appendix E).

Torrance Tests of Creative Thinking (TTCT)

The TTCT, developed by E. Paul Torrance in 1966, is a cognitive approach to assessing creativity and used to measure cognitive processes (Almeida, et al., 2008; Cooper, 1991; Fleenor & Taylor, 2003). There are two test forms of TTCT, the Verbal Form and Figural Form, including seven verbal subtests and three figural subtests, which are used to assess four constructs in creativity -- fluency, flexibility, originality, and elaboration. Each test form has two different sets: Verbal A, Verbal B, and Figural A, Figural B. The definitions of all four cognitive processes are widely recognized: “fluency” is the numbers of responses, “flexibility” is the number of categories in the responses, “originality” is the number of unique or unusual responses, and “elaboration” is the amount of detail in the responses.

There are three activities in the figural form including picture construction, picture completion, and lines. Within the three activities, five constructs addressed were measures including the fluency, elaboration, resistance to premature closure, originality, and abstractness of titles. Torrance (2008) reported the reliability coefficients for these five constructs were .99 for fluency, .96 for elaboration, .97 for resistance to premature closure, .97 for originality, and .97 for abstractness of titles. Torrance (2008) also reported the coefficient for the composite creativity index was .99.

In a study conducted by Simpson (2010), she reported the TTCT has a high rank in content, concurrent, and construct validity. The test retest reliability was reported to be significantly high based on the TTCT Figural tests (Simpson, 2010). Simpson’s study found that in the area of fluency, the correlation coefficient between TTCT Figural Form A and Figural Form B ranged from .96 to .99. In the area of originality, the correlation coefficients ranged from .91 to .99. Elaboration had correlation coefficients between .95 and .98. “Even though creativity seems to be composed of several factors that make its evaluation difficult and elusive, it is commonly accepted that the TTCT– which has been used internationally -- is one of the best forms of creativity measurement” (Almeida, et al., 2008, p. 54). The test was purchased through Scholastics Testing Service, Inc. (STS) and was sent to STS for professional scoring. Appendix F provides the STS contact information.

Senior Design Outcome Score

The tool to assess the senior design outcome is adapted from the Student Product Assessment Form (SPAF) developed by Sally M. Reis (1981). The SPAF was originally developed to aid teachers in assessing the quality of K-12 student products in gifted and talented programs. The 9 items assess both individual criteria as well as the overall excellence of the product. Items 1 through 8 are divided into the following three related categories:

> a) The Key Concept. This concept is always presented first and is printed in large type. It should serve to focus the rater's attention on the main idea or characteristic being evaluated.
> b) The Item Description. Following the Key Concept are one or more descriptive statements about how the characteristic might be reflected in the student's product.
> c) Examples. In order to help clarify the meaning of the items, an actual example of student work is provided. These examples are intended to elaborate upon the meaning of both the Key Concept and the Item Description. The examples are presented in italic following each item description.(Reis, 1981, p. 41)

Item 9 includes seven components involving an overall assessment of the product and which covers the product values and characteristics.

Due to the difficulties of developing a single instrument that would be effective in assess all types of products, Reis added a response category "Non-Applicable" to address the situations when some of the items do not apply to specific products.

Reis reported that the validity and reliability of the SPAF has been assessed (Reis & Renzuli, 2004). An expert review for content validity of the SPAF has been conducted by 20 experienced teachers of gifted and talented learners (Reis, 1981; Reis & Renzuli, 2004). The inter-rater agreement of the SPAF was determined in two separate phases. The first phase involved 19 experienced raters who rated a product of a first grader. The results were used to revise the SPAF. In the second phase, the revised SPAF was used to assess a second and third product. Twenty-two raters were involved in this phase. Reis (1981) reported that the agreement percentages on the second product were 100% and the third product were above 80%. The inter-rater reliability was generated involving 20 different products representing five different types including scientific, creative writing, social studies, audio visual, and interdisciplinary. Four experienced teachers rated the products. Reis used Ebel's (1951) technique in Guilford (1954) to inter-correlate the ratings obtained from her four different raters. The totals of inter-rater reliability of the four raters were .99. Permission to use and revise the SPAF was granted by Joseph S. Renzuli, Director of The National Research Center on Gifted and Talented, University of Connecticut (Appendix G).

The adaptation of SPAF was needed in this study because the original instrument was developed to aid teachers in assessing the quality of K-12 student products in gifted and talented programs. This may not fit with the purpose of this study's – measuring the mechanical engineering senior design outcomes. The adaption took multiple reviews by experts in both content and measurement.

In the adapted instrument, instead of highlighting "The Key Concept" and providing examples in the description, the researcher used the adapted items to make it workable during the process of data collection. For example, the original item "Is the purpose (theme, thesis, research question) readily apparent in the early stages of the student's product? In other words, did the student define the topic or problem in such a manner that a clear understanding about the nature of the product emerges shortly after a review of the material?” was adapted to “Is the design objective(s) clearly identified and readily apparent in the early stages of the team’s product development?”

The limitation of the adapted instrument was that it did not go through pilot testing, which can be useful to see how the items behave before or in actual data collection. The adapted instrument named the Judging Criteria rubric was presented in Appendix H.

Data Collection Phases

The data collection process was divided into three phases. Phase one was at the beginning of fall 2011 (the first three weeks), phase two was between weeks 14 and 15 of fall 2011, and phase three was between weeks 24 and 26 (before and during Engineering Days, Edays 2012). During phase one, students were engaged in becoming familiar with the requirements of the class and the design projects that were available, and completing the interests form used in determining which project they wished to work. Phase one could be characterized as the introductory phase of the course. During phase one, which spanned weeks three through 14, students learned of their team membership, and project assignment. During this time, students formed teams, began design task analysis, and created a project plan with the goal of producing a design solution proposal. Phase one can then be characterized as the introductory and preparatory phase, ending with the final design proposal presentation. Phase two, while very brief, culminates with the presentation of the team proposal both in oral and written format. Phase three commenced at the beginning of second semester and continued through Edays. During this time, students were engaged in design, fabrication, project plan execution, execution analysis, final testing, final product notebook development, and presentation. Phase three culminated in weeks 14 and 15 with the final data collection and Edays.

The first phase of data collection involved the demographic questionnaire, engineering knowledge score, and creativity score. The second phase involved the first team interaction scores. The third phase of data collection involved the second team interaction score and senior design outcome score. Figure 3.3 shows the data collection phases of the study.

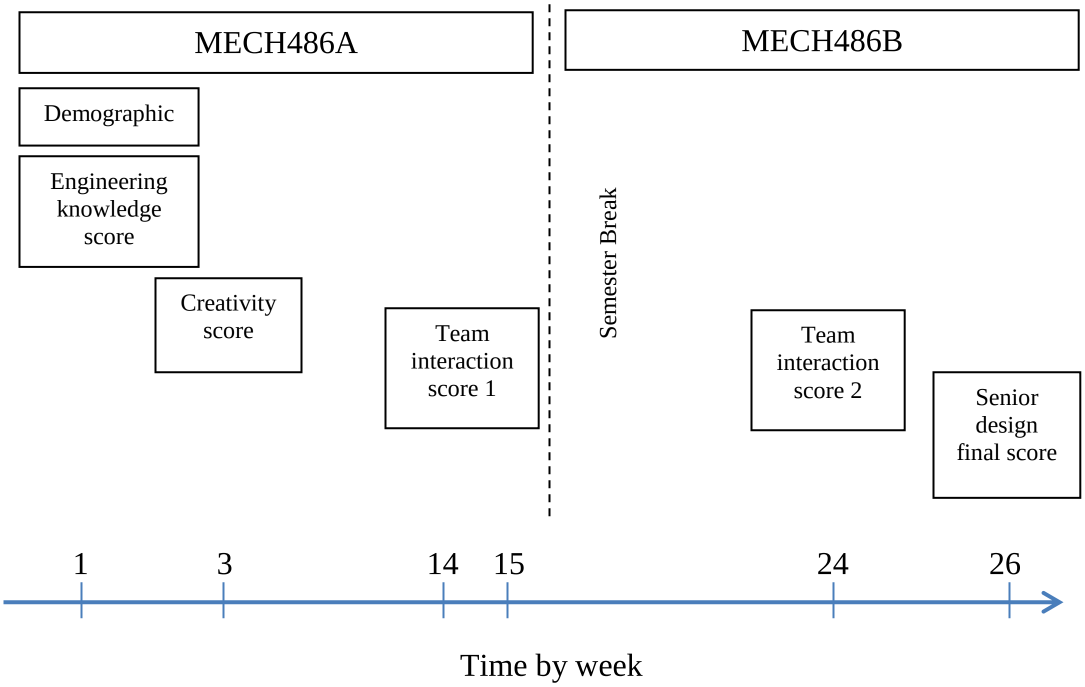


Figure 3.3. Data collection phases of the study

Data Collection Procedure

Data Collection Phase 1. The researcher conducted a presentation session on the research purpose and design to potential participants during week 1 of MECH486A.

Participation in this study was strictly voluntary and the voluntary nature of the participation was stressed. The students were advised that participation or non-participation in this study would have no impact on their final grade and they would not receive any other consideration. The briefing included, but was not limited, to how the research applies to the participants, and the significance of the study. The research briefing was important for achieving reliable and valid results. The researcher introduced the two instruments and set conditions for success in administering the two instruments. For the TTCT, it was important that the participants understand they are taking a creativity test and that it is suitable to give answers that may not fit into engineering norms. For the TCI, it was important the participants think about their teamwork environment (Anderson & West, 1998).

Study participants were asked to sign an informed consent form. Participants then completed the demographic questionnaire and the CSU “Student Permission to Release Academic Records” to facilitate researcher access to their academic records. After these data were collected, the participant link list was created under the direct supervision of the faculty principal investigator. The link list was used to link the data to the specific participant and create anonymity for participants in the study. Each participant received a unique five digit random number as their identifier. The participant can only be linked to their identifier through the link list, which was only known to the principal investigators and the researcher. Students used their unique identifiers for all phases of the study including in the completion of the creativity tests and team interaction questionnaire.

Once students were assigned to design teams (week 3), the researcher determined how many members of each team agreed to participate in the study. There were group size difference due to decisions by course Professors, project mentors/advisors, and the engineering design committee. As the researcher had no control over group assignment, the researcher had to decide the minimum number of group members that would be adequate to represent each group score on both instruments. The minimum number of group members that was considered fair will be not less than 4 students or 2/3rds of the total group members. If less than 4 students or 2/3rds of the team members volunteered for the study, the team was excluded from the study. Originally, there were 22 teams in the course. Two teams were excluded from the study because they had one or two members. The total numbers of teams potentially to be used in the study was 20 teams.

The researcher administered the TTCT (Figural Form A) during week 3 of fall 2011 with the course Professor's permission. The TTCT (Figural Form A) took about 30 minutes for students to complete. There are three activities and each activity was timed for 10 minutes. The researcher adapted and followed the instructions written by the author for test administration. At the end of the session, all the creativity test booklets were collected and screened for any unidentified participants (booklets without student's identifier). All participants completed the test and non-participants completed nine booklets. The researcher was unable to identify nine booklets completed by non-participants, and all booklets collected from participants, non-participants, and unidentified were mailed to STS for scoring.

Data Collection Phase 2. In the second phase of data collection, the researcher twice distributed the TCI to each group of participants. The first TCI was distributed during week 14 (Fall 2011) of MECH486A. Scores from the first TCI were used as a baseline group interaction score. The second TCI was distributed during week 24 (Spring

2012). There were 55 students from 12 teams who completed both team interaction questionnaires during the second phase of the data collection. This led to the researcher decision to focus on 12 final design outcomes or solutions for the study.

Data Collection Phase 3. The final phase of the data collection involved the product/outcome evaluation. The senior design outcomes scores for each team were determined using the Judging Criteria rubric. The Judging Criteria rubric was used during week 26 to score the senior design outcome from each team. Eleven engineering practitioners from local and international industries and three graduate students volunteered and were trained as raters using the instrument. The training session for the raters was conducted during week 26, the same day of the senior design showcase. The main purpose of the training was to control diffusion of treatment among the raters. Spool (1978) purports that rater training is effective and able to minimize rating errors. The raters then were divided into three teams, which gave each team four design team outcomes to evaluate during the showcase. Each rater team was composed of professional engineers and graduate students. The researcher conducted a post evaluation session among the raters to obtain their feedback about the adapted instrument.

The scores on each test and questionnaire, and the outcome scores were recorded and entered into IBM SPSS version 20 database. The data was managed and organized appropriately for analysis to answer this study research questions.

Data Analysis

The data were coded and analyzed using IBM SPSS version 20. The data were first screened to determine if there were errors or missing values. Any responses detected outside the acceptable ranges were “cleaned”. Since the sample for this study is considered to be small, any missing values were substituted appropriately. For example, in computing the engineering students’ GPA, if a required course grade was transferred and only “satisfactory” grade was provided, the researcher substituted the minimum passing grade (C equivalent to 2.00 points) required by CSU. In addition, if there were missing values in the team interaction survey, the researcher substituted the missing value with the team mean score for that item. After the data were organized, the appropriate statistical tests were conducted to answer the research questions as discussed in Table 3.3. Frequency distributions and descriptive statistics were performed on all background and demographic variables for the purpose of describing the sample. The reliabilities of the instruments used in the study was also analyzed and reported. Since the number of teams was small ($n = 12$), the exploratory data analysis (EDA) was performed to examine the relationships among creativity, engineering knowledge, and team interaction impact on the design solutions or outcomes.

Table 3.3

Research questions and type of statistical approach for data analysis

Research Question	**Variables**	**Data Analysis**
RQ1	*n* = 12 groups IV = team creativity score (Scale) DV = senior design outcome (Scale)	Descriptive Correlation
RQ2	*n* = 12 groups IV = team interaction score (Scale) DV = senior design outcome (Scale)	Descriptive Correlation
RQ3	*n* = 12 groups IV = team interaction score (Scale) DV = creativity score (Scale)	Descriptive Correlation
RQ4	*n* = 85 students IV = engineering course GPA DV = creativity score (Scale)	Descriptive Correlation
RQ5	*n* = 55 students IV = engineering course GPA DV = team interaction score (Scale)	Descriptive Correlation
RQ6	*n* = 12 groups IV = creativity score, engineering GPA, & team interaction score DV = senior design outcome	Descriptive Exploratory Data Analysis

CHAPTER 4: RESULTS

"Always remember that good science is transparent, not deceptive" - (Morgan, Reichert, & Harrison, 2002)

Overview

The results of the study are presented in this chapter. Quantitative data analysis is used to describe various characteristics of the study's voluntary participants and addresses each of the research questions explored in this study. The demographic data includes the age, gender, content major, current cumulative Grade Point Average (GPA), interest, and experiences in engineering that describe the sample. The students' engineering courses GPAs were reported and used as a proxy for the engineering knowledge levels of the participants. The Torrance Tests of Creative Thinking (TTCT) (Figural Form A) scores were collected to describe the level of creativity among the participants. The Team Climate Inventory (TCI) scores were collected twice throughout the study period and used to represent the interaction of the design team. The engineering product evaluation form was used to collect data on each design team outcome.

The variables were initially investigated using exploratory data analytic approaches (G. A. Morgan, Leech, Gloeckner, & Barret, 2004). For the purpose of discussion and presenting the results, the quantitative data are divided into six major sections. The first section describes the demographics of the sample. The second, third, fourth, and fifth sections describe the results of engineering knowledge, TTCT scores, TCI scores, and engineering design outcome scores. The final section discusses the relationships between each variable including: (a) creativity and senior design outcomes at the team level, (b) team interaction and senior design outcome at the team level, (c) the engineering knowledge and creativity at the individual level, and (d) engineering knowledge and team interaction at the team level. The relationship among creativity, engineering knowledge, and team interaction on the senior design outcome will also be discussed.

Demographics

The demographic questionnaire, the “Student Permission to Release Academic Records” form, and the consent form were distributed during the first week of the fall 2011 semester. The sample was students who are enrolled in Engineering Design Practicum (MECH486A) in the Mechanical Engineering Department, College of Engineering at Colorado State University. Eighty-eight of ninety-nine students from MECH486A class in fall 2011 volunteered to participate ($n = 88$, $N = 99$). The following findings were based on the 88 volunteered participants.

Participants’ ages. Ages of the sample ranged from 21 to 41 years old, with the mean age of 23.41 and mode and median of 22 years.

Participants’ genders. Mechanical engineering students in this study were predominantly male. There were six females, which represent seven percent of the sample. The small number of female participants limited the analysis examined by gender.

Participants’ majors. The mechanical engineering and engineering science majors were both part of the sample. There were four engineering science students enrolled in MECH486A which accounts for about 4.7% of the total sample. Therefore, the sample was treated as one group because they virtually follow the same undergraduate curriculum.

Grade Point Average (GPA). On average, the cumulative current GPA prior to MECH486A (overall GPA) within the sample is 3.00 with a standard deviation of .47 (*M* = 3.00, *SD* = .47). About 50% of the participants have a cumulative GPA above 3.00. In this study, the researcher used the MECH486A prerequisite course GPA (engineering GPA) that included courses related to mathematics, chemistry, physics, and mechanical engineering as a proxy to represent student engineering knowledge.

Skills and Experience. Three items with a five point Likert-Scale (i.e., 1= "None", 3= "Average", 5= "Outstanding") were developed for students to rate themselves on their individual skills and experience. For example, one of the item states "Engineering fabrication skills. How are you at building things?" The mean score for skills and experience indicated that all of the participants were above average (*M* > 3.80). The reliability of Cronbach's alpha for the skills and experience items was .52.

Interest. Four items with a five point Likert-Scale (i.e., 1= "Never", 3= "Sometimes", 5= "All the time") were developed for students to rate themselves on individual interests prior to the engineering design practicum. For example, one of the items states "Taking apart and/or building cars, computers, appliances, etc?" The mean score for participants' interest was above average (*M* > 3.00). The reliability of Cronbach's alpha for the four items of interest was .62.

Engineering Knowledge Prior to Senior Design

The prerequisite courses included courses related to mathematics, chemistry, physics, engineering science, and the required mechanical engineering courses, as illustrated in Figure 3.2 in Chapter 3. The total prerequisite credits earned by the participants ranged from 72 to 85 credits and about 97% of the participants earned above 80 credits prior to MECH486A. The engineering GPA was computed based on the MECH486A prerequisite courses that students must pass and complete prior to enrolling in the course.

Treatment of the data. The MECH486A prerequisite course GPA, including mathematics, chemistry, physics, and engineering courses, was computed based on the total credits of the related courses earned by individual students. Some students received transfer credit from other educational institutions in their transcripts, especially in mathematics, chemistry, and physics. A substitution was made for students who did not have a specific grade indicated in their transcript. For example, if a student received transfer credits with a satisfactory grade (TS) for a specific course, a grade C, equivalent to 2.00 points, was substituted. If a student received transfer credits with B- grade (TB-), a grade B-, equivalent to 3.334 points, was substituted. The judgment in substituting TS with 2.00 points (C grade) was made based on the CSU College of Engineering minimum requirement passing grade for them to be able to enroll in the Senior Design capstone course (Colorado State University, 2011). The team average score on the engineering GPA was used to represent the design team’s engineering knowledge. The Microsoft Excel 2010 software was utilized to compute the sub-disciplines GPA for mechanical engineering majors. The results of these calculations were then transferred to IBM SPSS version 20 for further statistical analysis. This SPSS data file will be called the first data set. Further exploratory statistics were mainly used to assess normality, and to determine if the major assumptions were met for inferential statistics. To represent design team scores, the student sample was sorted into the 12 design teams to which each had been assigned in early fall 2011 semester.

Results. At the beginning of the study, there were 88 students who volunteered to participate in this study. Table 4.1 shows the sub-discipline course GPA means and standard deviations of the participants prior to MECH486A.

The average engineering GPA among the sample is 2.94 with a standard deviation of .45 (*M* = 2.94, *SD* = .45, 95% CI [2.85, 3.04]). About 43% of the participants have an engineering GPA above 3.00.The paired sample *t*-test was executed to examine whether there was statistically significant difference between each sub-GPA, engineering GPA and the overall GPA. The assumptions of the paired *t*-test were checked. Based on Bulmer's (1979) skewness statistics guideline, the data are relatively normal. Bulmer (1979) proposed appropriate heuristics for interpreting the magnitude of skewness. With a skewness score of 0, the data are considered symmetrical or normally distributed, the absolute value from 0 to 1 is considered moderately normal, and if the skewness statistics have magnitude larger than 1, the data have skewed distribution. The dependent variable, the engineering GPA, has relatively normal distribution within the sample. The 95% confidence interval (CI) was used to report the index of certainty as shown in Table 4.1.

Table 4.1

Means and Standard Deviations of the Sub-discipline and Overall GPAs (n = 88)

Variable	*M*	*SD*	95% CI
Mathematics	2.58^{**}	.55	[2.47, 2.70]
Chemistry	2.95	.66	[2.81, 3.09]
Physics	3.10^{*}	.59	[2.98, 3.22]
Engineering Science	3.08^{*}	.55	[2.96, 3.19]
Mechanical Design	3.26^{**}	.46	[3.16, 3.35]
Mechanical Engineering	3.01	.52	[2.90, 3.12]
Engineering GPA	2.94^{**}	.45	[2.85, 3.04]
[a] Overall GPA	3.00	.47	[2.90, 3.10]

$^{*}p < .05$
$^{**}p < .001$
[a] Dependent Variable

A paired or correlated samples *t*-test indicated that students' on average scored significantly lower on their engineering GPA than their overall GPA, *t* (87) = -4.20, *p* < .001, *d* = .13. There was no statistically significant difference between the chemistry GPA and the overall GPA, *t* (87) = -.74, *p* = .460, *d* = .08, and between the mechanical engineering GPA and the overall GPA, *t* (87) = .18, *p* = .853, *d* = .01. Statistically significant differences were found between the mathematics GPA and the overall GPA, *t* (87) = -9.31, *p* < .001, *d* = .81, between the physics GPA and the overall GPA, *t* (87) = 1.94, *p* = .055, *d* = .18, between the engineering science GPA and the overall GPA, *t* (87) = 2.66, *p* = .009, *d* = .14, and the mechanical design GPA and the overall GPA, *t* (87) = 6.05, *p* < .001, *d* = .54. Students' on average scored significantly lower on their mathematics GPA than their overall GPA. For physic, engineering science, and mechanical design GPAs, students' scored significantly higher than their overall GPA.

The results of the *t*-test are presented in Table 4.2. The effect size was measured using Cohen's d, the difference between two means divided by the pooled standard deviation (Cohen, 1988). Cohen (1988) provides a convenient heuristics for interpreting the magnitude of d in the context of social science effect sizes: .20 is considered a small effect, .50 medium, and .80 large. Using Cohen's (1988) guidelines, the effect size between the mathematics GPA and overall GPA, and between the mechanical design GPA and overall GPA are moderate to higher than typical (Cohen, 1988; G. A. Morgan, et al., 2004). The effect size between the physics GPA and overall GPA, the engineering science GPA and overall GPA, and between student engineering GPA and the overall GPA are between small to typical.

Table 4.2

The t-tests, Significant p-values, and Effect Sizes of the GPA Pairs

GPA Pairs	df	*t*	*p*	*d*	Magnitude of d
Mathematics and Overall GPA	87	-9.31	< .001	.81	Large
Chemistry and Overall GPA	87	-.74	.460	.08	Small
Physics and Overall GPA	87	1.94	.055	.18	Small
Engineering Science and Overall GPA	87	2.66	.009	.14	Small
Mechanical Design and Overall GPA	87	6.05	< .001	.54	Medium
Mechanical Engineering and Overall GPA	87	.18	.853	.01	Small
Engineering GPA and Overall GPA	87	-4.20	< .001	.13	Small

Table 4.3 displays the relationships between the engineering GPA, overall GPA and the sub-GPA courses among the participants in this study. The assumptions of linearity between variables were checked and the sub-GPA, engineering GPA and overall

GPA measured have positive linear relationships between each other. The normality was assessed based on Bulmer (1979), and the Pearson Correlation assumptions were met. The bivariate correlation analysis shows that there are positive relationships between sub-GPAs except for chemistry and physics achievement, r (87) = .193, p = .071. In general, the sub-GPAs show a correlation coefficient above .50 with the engineering GPA. No statistically significant correlation was found between the chemistry GPA and physics GPA. Therefore, based on this analysis only the engineering GPA will be used for further analysis in examining the relationships between other main constructs in the study.

Table 4.3

Intercorrelations among sub-GPAs, Engineering GPA, and Overall GPA Prior to MECH486A (n = 88)

Variable	1.	2.	3.	4.	5.	6.	7.	8.
1. Mathematics	-	$.344^{**}$	$.458^{**}$	$.655^{**}$	$.345^{**}$	$.546^{**}$	$.751^{**}$	$.670^{**}$
2. Chemistry		-	.193	$.548^{**}$	$.241^{**}$	$.407^{**}$	$.518^{**}$	$.464^{**}$
3. Physics			-	$.536^{**}$	$.363^{**}$	$.521^{**}$	$.663^{**}$	$.619^{**}$
4. Engineering Science				-	$.569^{**}$	$.806^{**}$	$.906^{**}$	$.884^{**}$
5. Mechanical Design					-	$.702^{**}$	$.639^{**}$	$.646^{**}$
6. Mechanical Engineering						-	$.936^{**}$	$.923^{**}$
7. Engineering GPA							-	$.960^{**}$
8. Overall GPA								-

** $p < 0.01$

Design Team. There were 12 design teams who volunteered in this study, consisting of 55 participants. The design team sizes were unequal and ranged from three to six team members. The teams' mean score for each sub GPA, engineering GPA, and overall GPA were computed and averaged based on their team size. Table 4.4 shows the mean and standard deviation for each design team that participated in this study. Compared with the group mean for mathematics, chemistry, and physics team achievement, five teams were below group mean. For engineering science and mechanical design team achievement, there were seven teams below the group mean. For mechanical engineering and engineering GPA team achievement, there were eight teams below the group mean. Overall, based on the group mean score for each sub GPA, engineering GPA, and overall GPA, there were five teams that scored above the group mean and seven teams that scored below the group mean.

Table 4.4

Means and Standard Deviations of the Sub-discipline GPA for Participating Design Teams

Design Team			Math	Chemistry	Physics	Engineering Science	Mechanical Design	Mechanical Engineering	Engineering GPA	Overall GPA
EcoCar Powertrain	T1	*M*	2.49	2.88	2.67	3.11	3.22	2.99	2.86	2.89
	(*n* = 6)	*SD*	.45	.92	.84	.49	.59	.56	.49	.60
EcoCar Energy Storage	T2	*M*	2.48	2.77	3.38	3.07	3.37	2.89	2.89	2.98
	(*n* = 4)	*SD*	.43	.51	.50	.67	.52	.74	.58	.56
Formula SAE	T3	*M*	3.03	3.31	3.37	3.60	3.75	3.53	3.41	3.46
	(*n* = 5)	*SD*	.66	.29	0.59	.49	.38	.28	.36	.32
NASA Sheep Treadmill	T4	*M*	2.58	3.26	2.56	2.84	3.24	2.79	2.75	2.67
	(*n* = 3)	*SD*	.08	.63	.59	.14	.54	.65	.36	.57
Cell Bioreactor	T5	*M*	2.47	3.33	3.22	3.23	3.49	2.88	2.91	3.03
	(*n* = 3)	*SD*	.21	.58	.69	.32	.21	.17	.15	.20
John Deere Diesel DPF	T6	*M*	2.96	3.55	3.54	3.04	3.17	3.11	3.15	3.01
	(*n* = 4)	*SD*	.09	.53	.53	.70	.30	.59	.64	.69
Woodward Turbine	T7	*M*	2.67	2.89	3.13	3.00	2.85	2.85	2.87	2.94
	(*n* = 5)	*SD*	.44	.79	.68	.46	.28	.34	.35	.39
Algae Harvesting Unit	T8	*M*	2.80	2.80	3.04	2.96	2.87	2.78	2.84	2.92
	(n = 5)	*SD*	.30	.91	.40	.46	.48	.40	.33	.35
Charcoal Retort for Haiti	T9	*M*	2.89	3.18	3.39	3.15	3.07	3.15	3.13	3.21
	(n = 3)	*SD*	.35	.17	.42	.43	.50	.47	.38	.41
EIC Building Control	T10	*M*	2.40	3.06	2.97	2.74	3.20	2.65	2.68	2.83
	(n = 6)	*SD*	.24	.66	.50	.44	.36	.67	.46	.47
EIC Wind Turbine	T11	*M*	2.60	3.10	3.22	3.47	3.60	3.46	3.25	3.38
	(n = 6)	*SD*	.55	.86	.46	.49	.40	.51	.45	.46
Climbing Assist	T12	*M*	2.37	2.80	3.07	2.97	2.93	2.79	2.77	2.86
	(n = 5)	*SD*	.38	.41	.65	.59	.36	.18	.27	.33

Measure of Creativity

The Torrance Tests of Creative Thinking (TTCT) Figural Form A was administered and professionally scored by the Scholastic Testing Service (STS). Scores were reported as raw scores on a scale of 0 - 160, percentile ranks on a scale of 1-99%, and normalized standard scores with a mean of 100 and a standard deviation of 20 (*M* = 100, *SD* = 20). There are five separate norm-referenced assessments in the TTCT Figural Form A test, including fluency (number of responses given), originality (the uniqueness of the responses), abstractness of titles (the ability of the participant to produce good titles for each of the pictures represented in the TTCT), elaboration (extension of the basic images), and resistance to premature closure (completeness or closure of the test). In addition, there are 13 creativity strengths that were added to the average creativity score, that are considered the more complete overall creativity assessment, which are called the creativity index. The 13 creativity strengths consist of: (a) emotional expressiveness, (b) storytelling articulateness, (c) movement or action, (d) expressiveness of titles, (e) synthesis of incomplete figures, (f) synthesis of the lines, (g) unusual visualization, (h) internal visualization, (i) extending or breaking boundaries, (j) humor, (k) richness of imagery, (l) colorfulness of imagery, and (m) fantasy.

The TTCT Figural Form A test was administered to each study participant early in the fall 2011 semester before they were assigned to specific design teams. There are three main sections in TTCT Figural Form A to complete and participants were allowed 10 minutes to complete each section.

Treatment of the data. There were 85 students who completed the test during this study. There were no missing values reported by STS. Therefore the complete individual

TTCT Figural Form A test scores, including all the sub-elements, were entered in the first SPSS data set, combined with the engineering and sub discipline GPAs. The unique participant identifier was used to match the data. Further exploratory statistics were mainly used to assess normality, and to determine if the major assumptions were met for correlational analysis.

The researcher did not receive raw scores on each participant in the TTCT Figural Form A test. Therefore the internal consistency analysis of the TTCT Figural Form A was not performed. The creativity index was used to represent individual creativity levels. To represent the design team score on creativity, the sample was sorted into 12 design teams to which individuals had been assigned. The team average score of the creativity index was used to represent the design team creativity level.

Results. Table 4.5 shows the details of the group mean scores of each construct measured in the TTCT Figural A form. The creativity index mean among the participants was 106.74 with standard deviation of 11.96 (*M* = 106.74, *SD* = 11.96) with the possible test range score between 0 - 160. About 34% of the participants (about 30 participants) ranked above the 50th national percentile by grade (*M* = 100, *SD* = 20). The participants scored above 100 points in two of five constructs in the TTCT Figural Form A, including fluency and originality. For the purpose of correlation analysis with other main constructs in this study, the creativity index was used to represent a participant's creative ability as suggested by Torrance (1974).

Table 4.5

Means and Standard Deviations of TTCT Figural Form A Constructs (n=85)

Variable	*M*	*SD*	95% CI
Fluency	102.02	12.98	[99.16, 104.86]
Originality	109.59	13.60	[106.60, 112.57]
Abstractness of Titles	89.84	14.88	[86.57, 93.10]
Elaboration	85.57	11.71	[83.01, 88.15]
Resistance to Premature Closure	94.42	15.60	[90.99, 97.84]
Creativity Average score	96.37	9.70	[94.23, 98.49]
Creativity Index	106.74	11.96	[104.12, 109.37]

The correlation analysis was conducted to determine the relationship between constructs in creativity measured in the TTCT. Table 4.6 shows the results of the analysis. The linear assumptions were checked and the creativity constructs measured in the creativity test have positive linear relationships between each other. The normality was assessed and the Pearson Correlation assumptions were met. The bivariate correlation analysis shows a statistically significant relationship between construct measures in the TTCT Figural Form A. Overall, there was a statistical significance between constructs measured in TTCT except there was no significant relationship between the “originality” and “abstractness of titles”, *r* (84) = .12, *p* = .274, and between the “elaboration” and “resistance to premature closure”, *r* (84) = .15, *p* = .156. The interrater reliability was performed by the STS Scoring Center based on the recent study in October 2006. The 2006 results indicated the reliability coefficients were as follows for the five part of creativity assessment: Fluency = .99, Originality = .97, Elaboration = .96, Abstractness of Titles = .97, Originality = .97, and Resistance to Premature Closure

= .97 (Torrance, 2008, p. 45). A more recent study conducted by Simpson (2010) using pre and posttest design with two groups found that in the area of fluency, the test retest reliability (*r*) was between .96 and .99. In the area of originality, the test retest reliability ranged from .91 to .99. Elaboration had test retest reliability between .95 and .98.

Table 4.6

Intercorrelations for Constructs in Creativity Test, Creativity Average Score, and Creativity Index (n = 85)

TTCT Construct	1.	2.	3.	4.	5.	6.	7.
1. Fluency	-	$.611^{**}$	$.524^{**}$	$.230^{*}$	$.460^{**}$	$.804^{**}$	$.706^{**}$
2. Originality		-	.120	$.246^{*}$	$.485^{**}$	$.697^{**}$	$.670^{**}$
3. Abstractness of Titles			-	$.267^{*}$	$.484^{**}$	$.705^{**}$	$.648^{**}$
4. Elaboration				-	.155	$.503^{**}$	$.607^{**}$
5. Resistance to Premature Closure					-	$.770^{**}$	$.722^{**}$
6. Creativity Average Score						-	$.957^{**}$
7. Creativity Index							-

** $p < 0.01$
* $p < 0.05$

Table 4.7 represents the results for the 13 creativity strengths. More than 50% of the participants did not show evidence on their test booklets of seven of the creativity strengths including emotional expressiveness, expressiveness of titles, synthesis of incomplete figures, synthesis of the lines, internal visualization, humor, and fantasy. However, more than 50% of the participants showed repeated evidence (three or more instances) on four of the creativity strengths, including story telling articulateness, movement or action, colorfulness of imagery, and extending or breaking boundaries ([a] see last column of Table 4.7). Overall, the participants showed evidence of six of the creativity strengths (shows one or more evidences) including richness of imagery, unusual visualization, storytelling articulateness, movement of action, colorfulness of imagery, and extending or breaking boundaries ([b] see last two column of Table 4.7). Only the creativity index (the total of creativity average and creativity strength) was used for further analysis in examining the relationships between other main constructs in the study as suggested by Torrance (1974).

Table 4.7

Percentages of 13 Creativity Strengths Measured by TTCT exhibited by students (n = 85)

	Creativity Strength	Absence of evidence (%)	Some evidence (usually 1 or 2 times) (%)	Repeated evidence of a strength (usually 3 or more times) (%)
1	Emotional expressiveness	98.8	1.2	0
2	Synthesis of incomplete figures	91.9	5.8	2.3
3	Humor	81.4	17.4	1.2
4	Synthesis of the lines	75.6	20.9	3.5
5	Expressiveness of titles	68.6	27.9	3.5
6	Internal visualization	54.7	27.9	17.4
7	Fantasy	54.7	43.0	2.3
8	Richness of imagery	40.7	[b] 45.5	12.8
9	Unusual visualization	8.1	55.8	36.0
10	Storytelling articulateness	7.0	41.9	[a] 51.2
11	Movement or action	7.0	36.0	57.0
12	Colorfulness of imagery	5.8	43.0	51.2
13	Extending or breaking boundaries	0	7.0	93.0

[a] More than 50% showed 3 or more instances

[b] More than 50% showed 1 or more evidences

Design Team. The teams' mean score for each TTCT element were computed based on the team size. Table 4.8 summarizes the means and standard deviations of the TTCT constructs for each design team that participated in this study. For fluency and originality team level, six teams were below the TTCT group mean ($M < 102.01$ and $M < 109.59$ respectively). For the abstractness of titles, elaboration, and resistance to closure elements, there were four teams below the TTCT group mean ($M < 89.94$, $M < 85.58$ and $M < 94.41$ respectively). For the creativity average and creativity index, there were three teams below the TTCT group mean ($M < 96.36$ and $M < 106.74$ respectively). Overall, based on the TTCT group mean score for each TTCT construct, there were three teams that scored below the group mean and nine teams that scored above the TTCT group mean.

Table 4.8

Means and Standard Deviations of the TTCT Figural Form A Constructs for Participating Design Teams

Design Team			Fluency	Originality	Titles	Elaboration	Resistance to closure	Creativity Average	Creativity Index
EcoCar Powertrain	T1	*M*	98.67	104.50	89.50	86.33	87.50	93.33	102.50
	(*n* = 6)	*SD*	8.73	10.73	5.39	9.89	11.69	5.54	6.66
EcoCar Energy Storage	T2	*M*	104.25	108.25	104.25	83.25	101.50	100.25	110.75
	(*n* = 4)	*SD*	12.18	13.45	20.37	13.62	13.89	9.43	8.81
Formula SAE	T3	*M*	106.40	115.80	91.20	88.40	93.80	99.20	109.80
	(*n* = 5)	*SD*	12.46	12.03	9.58	9.50	16.92	9.36	10.89
NASA Sheep Treadmill	T4	*M*	96.67	106.00	78.33	86.33	82.00	90.00	98.33
	(*n* = 3)	*SD*	6.11	8.72	14.36	11.06	7.21	3.61	6.51
Cell Bioreactor	T5	*M*	100.00	117.00	76.67	86.33	108.00	98.00	108.00
	(*n* = 3)	*SD*	16.37	21.17	20.98	11.06	6.00	8.72	12.12
John Deere Diesel DPF	T6	*M*	101.75	112.00	92.75	78.75	95.50	96.50	106.25
	(*n* = 4)	*SD*	14.38	9.63	14.36	13.84	23.01	12.79	17.90
Woodward Turbine	T7	*M*	114.25	124.75	97.25	82.75	99.25	103.50	117.25
	(*n* = 4)	*SD*	10.34	10.01	11.24	4.50	16.64	4.65	4.99
Algae Harvesting Unit	T8	*M*	100.40	104.40	91.40	86.00	100.40	96.60	106.80
	(n = 5)	*SD*	21.61	17.94	23.41	24.32	18.12	19.88	23.44
Charcoal Retort for Haiti	T9	*M*	93.00	118.33	82.33	86.33	107.00	97.33	111.00
	(n = 3)	*SD*	21.70	22.50	22.19	11.06	27.18	14.57	21.00
EIC Building Control	T10	*M*	109.50	112.17	94.33	93.17	99.33	101.67	114.33
	(n = 6)	*SD*	13.02	18.26	10.93	9.66	16.82	9.63	11.06
EIC Wind Turbine	T11	*M*	102.17	107.17	96.50	89.83	101.33	99.50	109.50
	(n = 6)	*SD*	13.56	12.83	11.64	15.01	17.60	8.98	11.96
Climbing Assist	T12	*M*	105.40	109.60	94.80	81.80	88.60	96.20	106.60
	(n = 5)	*SD*	8.41	9.66	10.43	12.24	12.12	4.32	6.50

Team Interaction Measure

The Team Climate Inventory (TCI) developed by Anderson and West (1998) was used to measure team interaction in this study. There are two versions of the TCI, the long version with 61 items and the short version with 38 items. In this study, the researcher adapted and used only 36 items from the short version of TCI. The Exploratory Factor Analysis (EFA) was not conducted to determine the number of factors/constructs of the adapted instrument due to the limited sample who completed the TCI questionnaire in this study (n = 62) (Zhao, 2009). Therefore the five originally reported factors for this measure were used to analyze the means and standard deviations. The five factors included vision, participation safety, support for innovation, task orientation, and interaction frequency (Anderson & West, 1998). In this study, the TCI was administered at two different times. The first TCI measure was administered at the beginning of fall 2011 during MECH486A and the second one was administered at the end of spring 2012 during MECH486B as illustrated in Figure 3.3 in Chapter 3.

Treatment of the data. The second SPSS data set was created to analyze the TCI. Since the TCI score was used to represent team interaction within each design team, any missing value was replaced with the team mean score for each item that did not have a rating. New variables were computed including the pre and posttest average as well as difference of pre and posttest for each factor measured in the TCI. As with engineering knowledge and creativity scores, to represent the design team interaction score, the sample was sorted into the 12 design teams to which the students had been assigned. The third SPSS data set was created with the 55 participants who completed both the TCI pre and posttest. The previous scores for engineering knowledge and creativity were entered into this third data set that matched with participant's unique research ID. The pre and posttest mean differences were computed (posttest mean – pretest mean = difference) and used to represent the growth or decline of team interaction within each team. A positive magnitude was interpreted as growth of interaction within the team while negative sign will be inferred as decline in the interaction within the team. Further exploratory statistics were mainly used to assess normality, and to determine if the major assumptions were met for correlation statistics. The reliability of the TCI at pretest was analyzed using the Cronbach's alpha coefficient.

Results. The mean scores and its standard deviations at pre and posttest for each factor measured in the TCI is presented in Table 4.9. Nine items with a five point Likert-Scale (i.e., 1 = "Not at all", 2 = "Very little part", 3 = "Some part", 4 = "Most part", 5 = "Completely") were used to measure participants' team vision. For example, item 1 states "How clear are you about what your team objectives are". The mean score for vision at pre and posttest indicate that all of the participants agree that they understand most of their team vision with 95% CI [3.96, 4.31] and [3.83, 4.22], respectively. A dependent paired sample *t*-test was conducted to examine if there is a difference between students' pre and posttest on the vision factor. The results indicated that there was a statistically significant difference between pre and posttest on vision with small effect size, *t* (54) = 2.08, *p* = .042, *d* = .15. Students' on average scored higher on the vision factor on the pretest than on the posttest. The reliability of Cronbach's alpha for vision at pretest was .93.

Eight items with a five point Likert-Scale (i.e., 1 = "Strongly disagree", 2 = "Disagree", 3 = "Neither agree nor disagree", 4 = "Agree", 5 = "Strongly agree") were used to measure participation safety within the participants' team. For example, item 12 states "We have a … we are in it together attitude". The mean score for participation safety at pre and posttest indicated that all of the participants agree that their team members were participating and accepted among one another with 95% CI [4.12, 4.39], and [3.96, 4.37], respectively. A dependent paired sample *t*-test was conducted to examine if there was a difference between pre and posttest on the participation safety factor. The results indicated that there was no statistically significant difference between pre and posttest on participation safety factor, *t* (54) = 1.28, *p* = .205, *d* = .14. The reliability of Cronbach's alpha for participation safety at pretest was .85.

Eight items with a five point Likert-Scale (i.e., 1 = "Strongly disagree", 2 = "Disagree", 3 = "Neither agree nor disagree", 4 = "Agree", 5 = "Strongly agree") were used to measure support for innovation. For example, item 18 states "This team is always moving towards the development of new answers". The mean score for support for innovation at pre and posttest indicated that all of the participants agreed that their team members were supportive in developing new ideas with 95% CI [4.13, 4.35], and [3.88, 4.27], respectively. A dependent paired sample *t*-test was conducted to examine if there was a difference between pre and posttest on the support for innovation factor. The results indicate that there was a statistically significant difference between pre and posttest on support for innovation factor with small to medium effect size, *t* (54) = 2.18, *p* = .034, *d* = .28. Students' on average scored higher on the support for innovation factor on the pretest than on the posttest. The reliability of Cronbach's alpha for support for innovation at pretest was .80.

Seven items with a five point Likert-Scale (i.e., 1 = "To a very little extent", 2 = "Some extent", 3 = "Neither some nor great extent", 4 = "Great extent", 5= "To a very great extent") were used to measure task orientation. For example, item 36 states "Does the team have clear criteria which members try to meet in order to achieve excellence as a team?" The mean score for task orientation at pre and posttest indicated that all of the participants agreed that their team members were performing at their best to achieve excellent results with 95% CI [3.93, 4.25], and [3.77, 4.16], respectively. A dependent paired sample *t*-test was conducted to examine if there was a difference between pre and posttest on the task orientation factor. The results indicate that there was no statistically significant difference between pre and posttest on the task orientation factor, *t* (54) = 1.50, *p* = .139, *d* = .19. Students' on average scored higher on the task orientation factor on the pretest than on the posttest. The reliability of Cronbach's alpha for the task orientation factor at pretest was .88.

Four items with a five point Likert-Scale (i.e., 1 = "Strongly disagree", 2 = "Disagree", 3 = "Neither agree nor disagree", 4 = "Agree", 5 = "Strongly agree") were used to measure interaction frequency. The mean score for interaction frequency at pre and posttest indicated that all of the participants agreed that they met and interacted frequently with 95% CI [4.23, 4.53], and [4.06, 4.45], respectively. A dependent paired sample *t*-test was conducted to examine if there was a difference between pre and posttest on the interaction frequency factor. The results indicated that there was a statistically significant difference between pre and posttest on interaction frequency with small effect size, *t* (54) = 2.17, *p* = .034, *d* = .18. Students' on average scored higher on the interaction frequency factor on the pretest than on the posttest. The reliability of Cronbach’s alpha for interaction frequency at pretest was .84.

Table 4.9

Means, Standard Deviations, 95% CIs, Mean Differences and the Average Scores of the Factors in TCI at Pretest and Posttest

Factor	Pretest (*n*=62)			Posttest (*n*=57)			Mean Difference (*n* = 55)	Avg. (*n* = 55)	*SD*	95%CI
	M	*SD*	95% CI	*M*	*SD*	95% CI				
Vision	4.13	.68	[3.96, 4.31]	4.03	.73	[3.83, 4.22]	-.15	4.10	.66	[3.92, 4.28]
Participation Safety	4.25	.52	[4.12, 4.39]	4.17	.78	[3.96, 4.37]	-.12	4.22	.57	[4.07, 4.38]
Support for Innovation	4.24	.42	[4.13, 4.35]	4.08	.73	[3.88, 4.27]	-.19	4.18	.51	[4.05, 4.32]
Task Orientation	4.09	.62	[3.93, 4.25]	3.97	.74	[3.77, 4.16]	-.18	4.06	.53	[3.91, 4.20]
Interaction Frequency	4.38	.58	[4.23, 4.53]	4.26	.74	[4.06, 4.45]	-.19	4.35	.54	[4.20, 4.50]
Overall TCI	4.22	.46	[4.10, 4.34]	4.10	.67	[3.92, 4.27]	-.17	4.18	.51	[4.04, 4.32]

Overall, the mean score of all 36 items at pre and posttest indicated that there was a statistically significant difference with small effect size, t (54) = 2.33, p = .024, d = .21. Students' on average scored significantly higher on the pretest than on the posttest of the TCI. The strength of correlation between the items in each factor were small to larger than typical effect size (G. A. Morgan, et al., 2004). Table 4.10 shows the Cronbach's alpha scores and the inter-item correlation for the TCI at pretest. The Cronbach's Alphas of the TCI at pretest ranged from .80 to .93.

Table 4.10

Number of Scale Items and Cronbach Alpha Coefficient of the TCI at Pretest (n = 62)

Factor	Number of items	Cronbach Alpha Coefficient	Range of item total correlation
Vision	9	.93	$.37^{**}$ - $.82^{**}$
Participation Safety	8	.85	.12 - $.73^{**}$
Support for Innovation	8	.80	.06 - $.49^{**}$
Task Orientation	7	.88	$.31^{*}$ - $.64^{**}$
Interaction Frequency	4	.84	$.42^{**}$ - $.72^{**}$

** $p < 0.01$
* $p < 0.05$

Table 4.11 shows the results of the intercorrelation between factors measured in the TCI at pretest. The linear assumptions were assessed and met for all factors. The normality was checked based on Bulmer's (1979) guideline and factors 2, 3 and 4 were met. Therefore, the Pearson correlation was used to examine the correlation related with these factors. Spearman Rho was used to analyze the correlation related with factors 1, 5, and 6. The results indicate that there was a positive correlation between the factors of TCI at pretest with *p* values less than .001. The strength of relationships between TCI factors ranged from small to larger than typical (G. A. Morgan, et al., 2004).

Table 4.11

Intercorrelations for Factors in Team Climate Inventory at Pretest (n = 62)

Factor	*M*	*SD*	1	2	3	4	5	6
1. (Pre)Vision	4.13	.68	-	$.453^{**}$	$.439^{**}$	$.438^{**}$	$.547^{**}$	$.727^{**}$
2. (Pre)Participation	4.25	.52		-	$.656^{**}$	$.703^{**}$	$.591^{**}$	$.824^{**}$
3. (Pre)Innovation	4.24	.42			-	$.601^{**}$	$.453^{**}$	$.749^{**}$
4. (Pre)Task	4.09	.62				-	$.688^{**}$	$.863^{**}$
5. (Pre)Interaction	4.38	.58					-	$.800^{**}$
6. (Pre)TCI	4.22	.46						-

** $p < 0.01$

Table 4.12 shows the results of the dependent paired *t*-test between pre and posttest of the TCI factors. The results indicated that there was a statistically significant difference in three of five TCI factors between the pre and posttest. A statistically significant difference was found in vision, t (54) = 2.08, $p = 0.042$, $d = .15$, support for innovation t (54) = 2.18, $p = 0.034$, $d = .27$, and interaction frequency, t (54) = 2.17, $p = 0.034$, $d = .18$. Students' on average scored significantly higher on the vision, support for innovation, and interaction frequency factors on the pretest than on the posttest. The effect size was reported to be small to moderate based on Cohen (1988). Overall, there was a statistically significant difference between pre and posttest of TCI with a small effect size, t (54) = 2.33, $p = 0.024$, $d = .21$. Students' scored significantly higher on the TCI on the pretest than on the posttest.

The paired samples correlations test was performed to assess test retest reliability of the TCI. There was a positive correlation between pre and posttest of TCI, r (54) = .61, $p < .001$. This positive correlation indicated that participants who scored high on the TCI pretest were very likely to score high on the TCI posttest, and participants who scored low were very likely to score poorly on the TCI posttest.

Table 4.12

Means, Standard Deviations, t-tests, Effect Sizes, and Significant p-values of the Factor in TCI at Pretest and Posttest

Factor	Pretest (n = 62)		Posttest (n = 57)		t (n = 55)	d	p-value
	M	SD	M	SD			
1. Vision	4.14	.69	4.03	.73	2.08	.15	.042
2. Participation Safety	4.26	.52	4.17	.78	1.28	.14	.205
3. Support for Innovation	4.24	.42	4.08	.73	2.18	.27	.034
4. Task Orientation	4.09	.62	3.97	.74	1.50	.18	.139
5. Interaction Frequency	4.38	.58	4.26	.74	2.17	.18	.034
6. Overall TCI	4.22	.46	4.10	.67	2.33	.21	.024

Design Team. Table 4.13 shows the results of pre and posttest mean differences of the factors measured in the TCI within each team. The pre and posttest mean differences were used to represent the growth or decline of team interaction within each team. As described earlier in this section, the positive magnitude indicated growth of interaction within the team and the negative sign will refer to the decreasing interaction within the team. There were five teams that indicated growth/changes in their team vision along the design process and one team rated was remained with the same team vision. Seven teams had positive participation environment. Five teams showed their support on innovation and positive task orientation within their teams. Four teams had positive scores on their team interaction. Overall, six teams had positive difference scores based on the average mean differences of the TCI.

Table 4.13

Average Pre and Posttest Means, Standard Deviations, and Mean Differences of TCI for Participating Design Teams

Design Team			Vision	Participation Safety	Support for Innovation	Task Orientation	Interaction Frequency	Overall
EcoCar Powertrain	T1	*M*	4.43	4.29	4.22	4.18	4.31	4.29
	(*n* = 6)	*SD*	.50	.60	.40	.58	.43	.47
		Mean Diff.	-.43	-.58	-.56	-.40	-.37	-.47
EcoCar Energy Storage	T2	*M*	4.57	4.52	4.41	4.48	4.87	4.57
	(*n* = 4)	*SD*	.08	.35	.21	.12	.18	.16
		Mean Diff.	.08	.09	.19	.11	-.12	.07
Formula SAE	T3	*M*	4.54	4.31	4.65	4.37	4.67	4.51
	(*n* = 5)	*SD*	.50	.60	.58	.34	.33	.44
		Mean Diff.	-.11	.37	-.05	.69	.05	.19
NASA Sheep Treadmill	T4	*M*	4.42	4.56	4.48	4.40	4.67	4.51
	(*n* = 3)	*SD*	.25	.50	.29	.28	.26	.28
		Mean Diff.	-.11	.37	.12	.24	.17	.16
Cell Bioreactor	T5	*M*	4.07	3.85	4.10	4.07	4.06	4.03
	(*n* = 3)	*SD*	.23	.26	.19	.33	.44	.14
		Mean Diff.	-.44	-1.21	-.54	-.52	-.79	-.70
John Deere Diesel DPF	T6	*M*	4.68	4.43	4.33	4.34	4.43	4.44
	(*n* = 4)	*SD*	.21	.28	.58	.38	.16	.26
		Mean Diff.	.08	.12	.16	-.11	.12	.08
Woodward Turbine	T7	*M*	4.22	4.10	4.01	3.93	4.65	4.18
	(*n* = 5)	*SD*	.37	.26	.34	.46	.27	.27
		Mean Diff.	.00	.15	.02	-.71	-.40	-.19
Algae Harvesting Unit	T8	*M*	3.95	4.62	4.38	4.29	4.45	4.34
	(*n* = 5)	*SD*	.57	.36	.30	.44	.54	.40
		Mean Diff.	.09	-.60	-.52	-.91	-.30	-.45

Charcoal Retort for Haiti	T9	*M*	4.26	4.71	4.43	4.14	4.71	4.45
	(*n* = 3)	*SD*	.57	.40	.36	.43	.29	.40
		Mean Diff.	.15	.08	.15	.00	-.08	.06
EIC Building Control	T10	*M*	3.74	4.15	4.07	3.91	3.99	3.97
	(*n* = 6)	*SD*	.47	.53	.49	.66	.62	.51
		Mean Diff.	-.93	-.09	-.22	-.21	-.40	-.37
EIC Wind Turbine	T11	*M*	2.83	3.42	3.53	3.20	3.59	3.32
	(*n* = 6)	*SD*	.59	.81	.65	.33	.73	.58
		Mean Diff.	.18	-.25	-.61	-.40	-.43	-.30
Climbing Assist	T12	*M*	4.10	4.15	3.98	3.84	4.31	4.08
	(*n* = 5)	*SD*	.37	.24	.48	.34	.31	.27
		Mean Diff.	-.16	.05	-.02	.37	.37	.12

Senior Design Outcome Score

The Judging Criteria rubric was adapted from the Student Product Assessment Form (SPAF), an original instrument developed by Reis (1981). The adapted instrument consisted of two main sections named “Technical Approach and Final Design Solution” and “Overall Assessment”. The combined scores are then referred as to the Senior Design Outcome Score for each team. Sections had 12 items and 7 items, respectively (refer to Appendix H for details of the adapted instrument). The first section of the judging criteria asked questions related to the design process in general using a five point Likert-scale (i.e., 1 = “To a limited extent”, 3 = “Somewhat”, 5 = “To a great extent”). For example, item 3 stated “Did the team focus or clearly define the design problem so it represents a relatively specific problem within a larger area of the study”. The second section of the judging criteria consisted of statements related to overall features of the product or design solution and rated using a five point Likert-scale (i.e., 1 = “Poor”, 2 = “Below average”, 3 = “Average”, 4 = “Above average”, and 5 = “Outstanding”). For example, item 14 stated “Achieved objectives stated in plan”.

The researcher collected the engineering design outcome score by having a group of raters evaluate the senior design projects. The product or design solution evaluation was conducted in week 26 during the senior design showcase (spring 2012), as illustrated earlier in Figure 3.3. Fourteen raters were trained for one hour to use the instrument of Judging Criteria on the same day of the showcase. Eleven of them were professional engineers from the industries and the other three were graduate students. Nine of the industrial raters had more than 10 years of experience in the professional engineering field. Ten of the raters were electrical engineers. Two of the graduate students are doing their doctoral study at the College of Engineering CSU and the other one is at the School of Education CSU. Four of the industrial raters were CSU alumni and probably had been exposed to the same senior design experience during their undergraduate studies at CSU.

Before the researcher ended the training session, the raters were divided into three teams composed of engineers and graduate students. Each rating team was assigned four projects to evaluate in two hours' time using the Judging Criteria. While individual scoring from each rater was stressed, the rating teams were advised to work together to interview the student design team about their projects. It was proposed to the rater teams that they could interview the design team before evaluating their product or design solution. In this study, there were 12 different types of products related to the mechanical engineering field that were assessed. Each team product was coded as T1 to T12 as shown earlier in Table 4.3. To quantify the degree of consistency among the raters, the researcher computed the index of interrater reliability using the intraclass correlation approach. The intraclass correlation is usually used to assess the consistency of the rating (Huck & Cormier, 1996).

Treatment of the data. Since there is only one product score for each team, a fourth SPSS data set was created to enter the team design outcome score. No missing value was found in the data set. A new variable called "Senior Design Outcome Score" was computed by adding the "Technical Approach and Final Design Solution" score with the "Overall Assessment" score. The interrater reliability was computed using the intraclass correlation technique proposed by Ebel (1951).

Results. Table 4.14 shows the results of the judging criteria for all 12 design teams. Overall, five design teams scored above the team mean on technical approach and final design solution section (*M* = 47.62). For the overall assessment section, only four design teams scored above the team mean score (*M* = 28.91). The summation of these two sections was referred as Senior Design Outcome Score. With a total score of 95 points possible, five teams scored above 76.52 points.

Table 4.14

Average Score of the Judging Criteria for the Participating Design Teams

Project	Technical Approach and Final Design Solution 12 item (out of 60)	Overall Assessment 7 item (out of 35)	Senior Design Outcome Score 19 item (out of 95)
T1[a]	53.75[a]	32.00[a]	85.75[a]
T2	41.25	26.25	67.50
T3[a]	49.00[a]	28.80	77.80[a]
T4[a]	51.60[a]	30.40[a]	82.00[a]
T5	44.80	27.80	72.60
T6	46.00	26.75	72.75
T7[a]	54.40[a]	33.60[a]	88.00[a]
T8	46.80	26.40	73.20
T9	44.50	28.75	73.25
T10[a]	48.60[a]	31.00[a]	79.60[a]
T11	44.20	27.40	71.60
T12	46.50	27.75	74.25
Mean Score	47.62	28.91	76.52

[a] *Scored above the mean score*

To obtain the interrater reliabilities, Reis (1981) utilized the techniques described by Ebel (1951). Therefore, the researcher used the same technique to compute the interrater reliabilities of the adapted instrument. Ebel's approach to the reliability of ratings essentially intercorrelates the ratings obtained from different raters. The reliability for the mean ratings for the five raters was computed using Ebel's formula as follows:

$$r_5 = \frac{M_{\bar{x}} - M}{M_{\bar{x}}}$$

where,

r_5 = the reliability of ratings for five raters

$M_{\bar{x}}$ = variance for persons

M = variance for error

The inter-rater reliability was computed using an inter-rater reliability calculator retrieved from Medical Education Online (MEO) webpage http://www.med-ed-online.org/rating/reliability.html (Solomon, n.d.). The MEO is a peer-reviewed international open access journal for disseminating information on the education and training of physicians and other health care professionals.

Table 4.15 represents the results of the interrater reliability analysis for the Judging Criteria instrument within each project as well as across all 12 projects. The interrater reliability analysis was split into two sections because each section used a different scale of measurement. Overall, the estimated results indicated that the interater reliability for the Judging Criteria instrument was .55 for Technical Approach and Final Design Solution, and .68 for Overall Assessment.

Table 4.15

Means, Standard Deviations, and Interrater Reliability of the Judging Criteria

Project	Number of raters	Technical Approach and Final Design Solution (12 items)			Overall Assessment (7 items)		
		Team Mean	Std. Dev.	Reliability	Team Mean	Std. Dev.	Reliability
T1	5	53.75	3.27	.45	32.00	1.87	.48
T2	4	41.25	8.06	.63	26.25	4.11	.64
T3	5	49.00	6.67	.76	28.80	3.11	.39
T4	5	51.60	4.51	.61	30.40	2.30	.53
T5	5	44.80	9.18	.77	27.80	4.87	.82
T6	4	46.00	4.55	.27	26.75	3.30	.51
T7	5	54.40	5.22	.80	33.60	1.67	.59
T8	5	46.80	6.34	.62	26.40	4.56	.79
T9	4	44.50	3.87	.09	28.75	3.30	.61
T10	5	48.60	3.05	.37	31.00	1.00	.50
T11	5	44.20	5.36	.65	27.40	3.58	.61
T12	4	46.50	7.05	.57	27.75	4.03	.77
Interrater reliability based of 5 raters		49.14[a]	3.85[a]	.55	29.68[a]	2.49[a]	.68

[a] The mean and standard deviation are based on the averaged ratings for each team product rated

Post evaluation. The post evaluation session was conducted after the raters completed scoring the senior design projects. The rater demographic and feedback on the judging criteria evaluation rubric survey was administered. The descriptive statistics indicate that 13 raters were male and one female. Seven of the raters declared themselves as engineer, four engineering management, and three graduate students. Ten of the raters selected electrical engineering as their field, one reliability engineering, one education, and one software engineering. Eight of the rates have more than 10 years in their current position. Four of the raters are CSU alumni.

Six items were developed to assess feedback on the judging criteria evaluation rubric. A three point scale (i.e., 1 = Less than 10 minutes, 2 = 10 to 15 minutes, 3 = More than 15 minutes) was developed to assess how long the rater took to evaluate each project. For example, item 6 states “On average how long did it take you to evaluate each project?” About 86% or 12 of the raters took more than 15 minutes to assess one project. A four point Likert-Scale (i.e., 1 = Strongly disagree, 2 = Disagree, 3 = Agree, 4 = Strongly agree) was developed to assess whether the items were easy to understand. For example, item 7 states “Every item in the evaluation form was easy to understand for evaluation”. All of the raters agree that every item was easy to understand for evaluation with five of them rating “strongly agree”. A five point Likert-scale (i.e., 1 = Very poor, 2 = Poor, 3 = Fair, 4 = Good, 5 = Very good) was developed to examine the raters perception on the evaluation rubric. For example, item 8 states “Overall how would you rate this evaluation form?” All of the raters agree that the instrument was well developed with four of them rating “very good”. Three additional open ended questions were developed to ask raters’ perception about the evaluation form including the easiest and the most difficult item to assess. For example, item 10 states “Which item(s) were most difficult to evaluate? Why? (You can list more than 1)” There was no common item or agreement among the raters on which item is the easiest or difficult to assess. The responses are varied and some of them found some of items in the first section (Technical Approach and Final Design Solution) hard to assess (i.e., variation of the design methods, use of resources, team dynamic), while some others found item in the second section (Overall Assessment) hard to assess (i.e., originality).

Analysis of Correlation

In this section, the correlation analysis related to the research questions presented in Chapter 1 is discussed.

Relationship Between Creativity and Senior Design Outcome

1. *What is the relationship between the team composite creativity score and senior design outcome?*

SPSS data set four was used to run the analysis (*n* = 12). To investigate if there was a statistically significant association between the team average creativity index and senior design outcome, Pearson correlations were computed. The linear assumptions were checked and the assumption of normality was met. The scatter plot indicates that there was a relatively linear relationship between team TTCT Figural Form A constructs and creativity index with senior design outcome. The skewness statistic indicated that the variables were relatively normally distributed and the absolute value ranged from .07 to

.79 (Bulmer, 1979). Table 4.16 shows the overall results of the correlation analysis between creativity and its sub-constructs with senior design outcome.

The results indicated that only TTCT Resistance to Premature Closure had significant correlation with the Technical Approach and Final Design Solution, r (11) = -.58, p = .048. There was no statistical significance found for the other pairs. Overall, the analysis of correlation indicated very low, negative, and non-significant correlation between creativity and design outcome, r (11) = -.012, p = .971. This led to the summary that in this study, the design team creativity level had no association with the senior design outcome score.

Table 4.16

Intercorrelations between TTCT Figural Form A Constructs, Creativity Index and Senior Design Outcome Score (n = 12)

TTCT Construct	Product Assessment		
	Technical Approach and Final Design Solution	Overall Product Assessment	Senior Design Outcome Score
Fluency	.282	.352	.317
Originality	.135	.370	.229
Title Abstractness	-.160	-.109	-.145
Elaboration	.063	.229	.128
Resistance to premature closure	-.581*	-.313	-.496
Average score	-.186	.082	-.089
Creativity Index	-.124	.180	-.012

* Correlation is significant at the 0.05 level (2-tailed)

Relationship Between Team Interaction and Senior Design Outcome

2. *What is the relationship between the team interaction score and senior design outcome?*

SPSS data set four was used to run the analysis (*n* = 12). The linear assumptions were checked and the assumption of normality was met. The scatter plot indicates that there was a relatively linear relationship between team interaction growth/decline measured by TCI factors with senior design outcome scores. The skewness statistic for TCI factors pre and posttest differences indicated that the variables were relatively normally distributed with an absolute magnitude ranging from .06 for TCI Interaction Frequency to .48 for overall TCI difference except for TCI Vision difference and TCI Participation Safety difference (Bulmer, 1979). Therefore the Spearman Rho correlation was utilized to examine the correlation related to TCI Vision difference and TCI Participation Safety difference. Table 4.17 shows the overall results of the correlation analysis between creativity and its constructs with senior design outcome.

Overall, the analysis of correlation indicated a negative and non-significant correlation between the team interaction score and senior design outcome score. The correlation between team TCI pre and posttest mean difference score and senior design outcome score was *r* (11) = -.11, *p* = .743. The results suggest that there was no significant correlation between TCI factors differences with the senior design outcome.

Table 4.17

Intercorrelations between TCI Factors Difference and Senior Design Outcome Score (n = 12)

TCI Factor Pretest and Posttest Difference	Product Assessment		
	Technical Approach and Final Design Solution	Overall Product Assessment	Senior Design Outcome Score
Vision	-.474[a]	-.530[a]	-.460[a]
Participation Safety	.284[a]	.221[a]	.329[a]
Support for Innovation	-.066	.010	-.039
Task Orientation	-.144	-.147	-.149
Interaction Frequency	-.019	-.200	-.089
Overall TCI	-.086	-.133	-.106

[a] Spearman Rho Correlation Coefficient

Relationship Between Team Interaction and Creativity

3. *What is the relationship between the team composite creativity score and team interaction score?*

SPSS data set four was used to run the analysis (*n* = 12). Table 4.18 summaries the results of the correlation analysis between TCI factors, TTCT constructs and creativity index. The analysis of correlation indicated a negative and non-significant correlation between team TCI pre and posttest mean difference score and creativity index score, *r* (11) = -.11, *p* = .740. The only significant correlation coefficient was found between TCI factors on Interaction Frequency with TTCT constructs on Resistance to

Premature Closure, *r* (11) = .61, *p* = .035. This finding suggests that there was no significant correlation between team interaction and creativity.

Table 4.18

Intercorrelations between TCI Factors Difference, TTCT Creativity Constructs, and Creativity Index (n = 12)

TCI Factor Pretest and Posttest Difference	TTCT Figural Form A Construct						
	Fluency	Originality	Title abstractness	Elaboration	Resistance to premature closure	Average score	Creativity Index
Vision	-.204[a]	-.126[a]	.288[a]	-.180[a]	.337[a]	.088[a]	.123[a]
Participation Safety	.252[a]	.287[a]	.158[a]	-.187[a]	-.452[a]	.046[a]	.102[a]
Support for Innovation	.088	.336	.137	-.484	-.181	.015	.104
Task Orientation	-.067	-.018	-.008	-.044	-.424	-.221	-.216
Interaction Frequency	-.100	-.198	.128	-.442	-.610*	-.400	-.354
Overall TCI	-.008	.068	.193	-.375	-.406	-.156	-.107

[a] Spearman Rho Correlation Coefficient
* Correlation is significant at the 0.05 level (2-tailed)

Relationship Between Engineering Knowledge and Creativity

4. *What is the relationship between the composite engineering course GPA and creativity score?*
    a. *What is the relationship between mathematics courses GPA and creativity score?*
    b. *What is the relationship between physics courses GPA and creativity score?*
    c. *What is the relationship between chemistry courses GPA and creativity score?*
    d. *What is the relationship between engineering sciences courses GPA and creativity score?*
    e. *What is the relationship between engineering design courses GPA and creativity score*

The first SPSS data set was used to analyze this question (*n* = 85). To investigate if there was a statistically significant association between student engineering GPA and the creativity index, Pearson correlations were computed. The linear assumptions were checked and the assumption of normality was met. Table 4.19 shows the overall results of the correlation analysis between engineering knowledge and its sub-discipline and creativity index.

The correlation analysis shows there was no significant relationship found between the engineering sub-GPA and the TTCT creativity index. The results also show that there was low and no statistically significant correlation between other sub-GPAs and the TTCT creativity index. In other words, these results suggest that there was no association between engineering GPA and it sub-GPAs with student's creativity.

Table 4.19

Intercorrelations for Engineering Knowledge and TTCT Creativity Index (n = 85)

Variable	Creativity Index	*p*-value
1. Mathematics	-.003	.981
2. Chemistry	.052	.638
3. Physics	.126	.252
4. Engineering Science	.024	.826
5. Mechanical Design	-.011	.919
6. Mechanical Engineering	.001	.996
7. Engineering GPA	.031	.779

Relationship Between Engineering Knowledge and Team Interaction

5. *What is the relationship between the composite engineering knowledge GPA and team interaction score?*

Using the Pearson correlation at team level (*n* = 12), the analysis indicated a negative and non-significant correlation between engineering knowledge and team interaction pre and posttest average score, and between engineering knowledge and team TCI pre and posttest mean differences, *r* (11) = -.05, *p* = .366, and *r* (11) =-.29, *p* = .360, respectively. However, at the individual level (*n* = 55), a significant negative correlation was found between participants' current overall GPA and team interaction pre and posttest average scores for individual students, *r* (54) = -.29, *p* = .030. This finding suggested that students with high overall GPA tended to score low on team interaction.

Relationship Among Creativity, Engineering Knowledge, and Team Interaction on Senior Design Outcome

6. *What is the interaction between creativity, engineering knowledge, and team interaction on senior design outcome?*

The sample size of this study is not sufficient to run inferential statistics to examine the relationship between constructs of this study (*n* = 12). Therefore the exploratory data analysis (EDA) proposed by Morgan, Leech, Gloeckner, and Barrett (2004) were utilized to understand and explore the data. Two general methods for EDA including generating box and whisker plots for each construct and descriptive statistics (including mean, standard deviation, and skewness) were used to describe the data. Box and whisker plots are useful for identifying variables with extreme scores, which can make the distribution skewed. The descriptive statistics for each construct have been discussed earlier in this section.

Figure 4.1 displays the boxplot quartile distributions for creativity level measured by the TTCT creativity index for participants in each design team. There were six design team creativity median scores above the group mean (*M* > 106.74). The interquartile ranges across all 12 design teams were quite different (as shown by the lengths of the boxes). The boxplots showed that Charcoal Retort for Haiti team had the higher median score on the creativity index compared to other teams. The LANL/Solix – Acustic

Harvesting of Algae team had a greater interquartile range, which indicated that more variation of scores was present on the creativity index score. The boxplot for the NASA Sheep Treadmill team showed the least interquartile range variation for the creativity index score. The boxplots also indicated that none of the design team data sets showed any suspiciously outlying values. Overall, the 12 design teams' creativity data sets looked as if they were generally not distributed in a similar way. The notable variation in interquartile distributions among the teams was due to the small team size (three to six students per team) assigned to complete the senior design tasks.

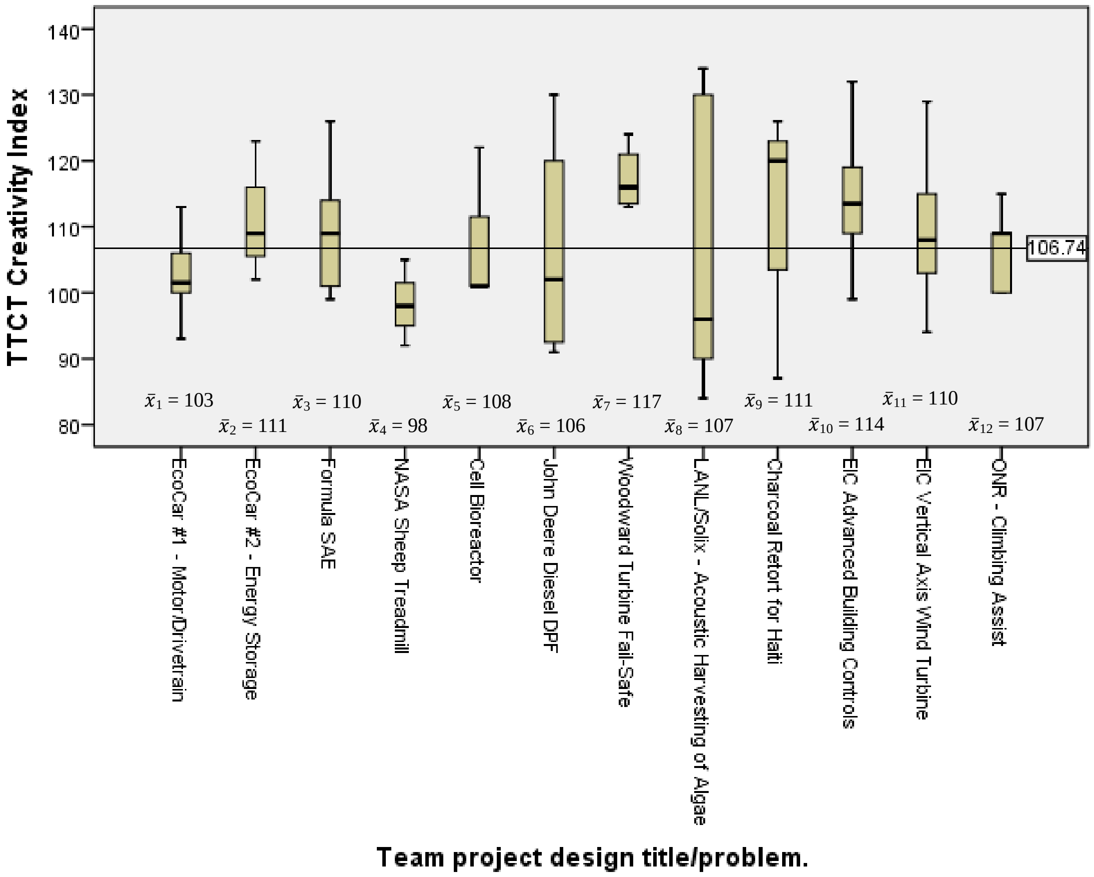


Figure 4.1. Comparative boxplot of the TTCT creativity index for each senior design teams with group mean of 106.74

Figure 4.2 displays the boxplot quartile distributions for engineering GPA measured by MECH486A prerequisite course GPAs for participants in each design team. There were five design team engineering knowledge median scores above the group mean (*M* > 2.94). The interquartile ranges across all 12 design teams were quite different. There were two design team data sets (Formula SAE and Woodward Turbine Fail-Safe) that showed high outlier values. The boxplots indicate that the Formula SAE team had the higher median score on engineering GPA compared to other teams. The John Deere Diesel DPF team had a greater interquartile range which indicated that more variation of scores was present on the engineering GPA. The boxplot for the Cell Bioreactor team showed the least interquartile range variation of engineering GPA. The small and unequal team size and extreme values may have caused the data not to be distributed in a similar way.

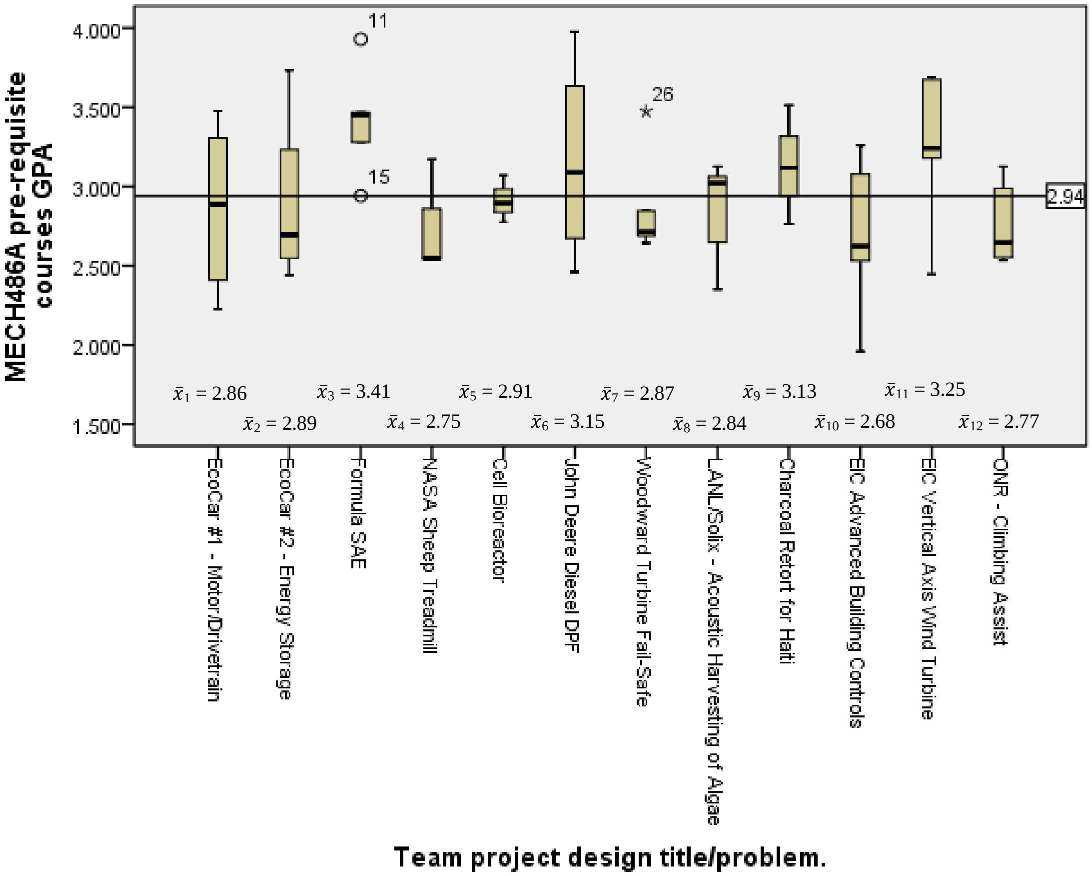


Figure 4.2. Comparative boxplot of the engineering GPA for each senior design team with group mean of 2.94

Figure 4.3 displays the boxplot quartile distributions for team interaction measured by the TCI mean difference at pre and posttest for participants in each design team. There are eight design team interaction median scores above the group mean (*M* > -.17). One design team had a median score equal to the group mean which could be interpreted as the team interaction remained the same throughout a yearlong project. The boxplots indicated that the Formula SAE team had the higher median score on TCI mean difference compared to other teams. The small and unequal team size and extreme values may have caused the data not to be distributed in a similar way. The EcoCar #1 – Motor/Drivetrain team had a greater interquartile range, which indicated that more variation of scores was present on the TCI mean difference score. The boxplot for NASA Sheep Treadmill team showed the least interquartile range variation TCI mean difference score.

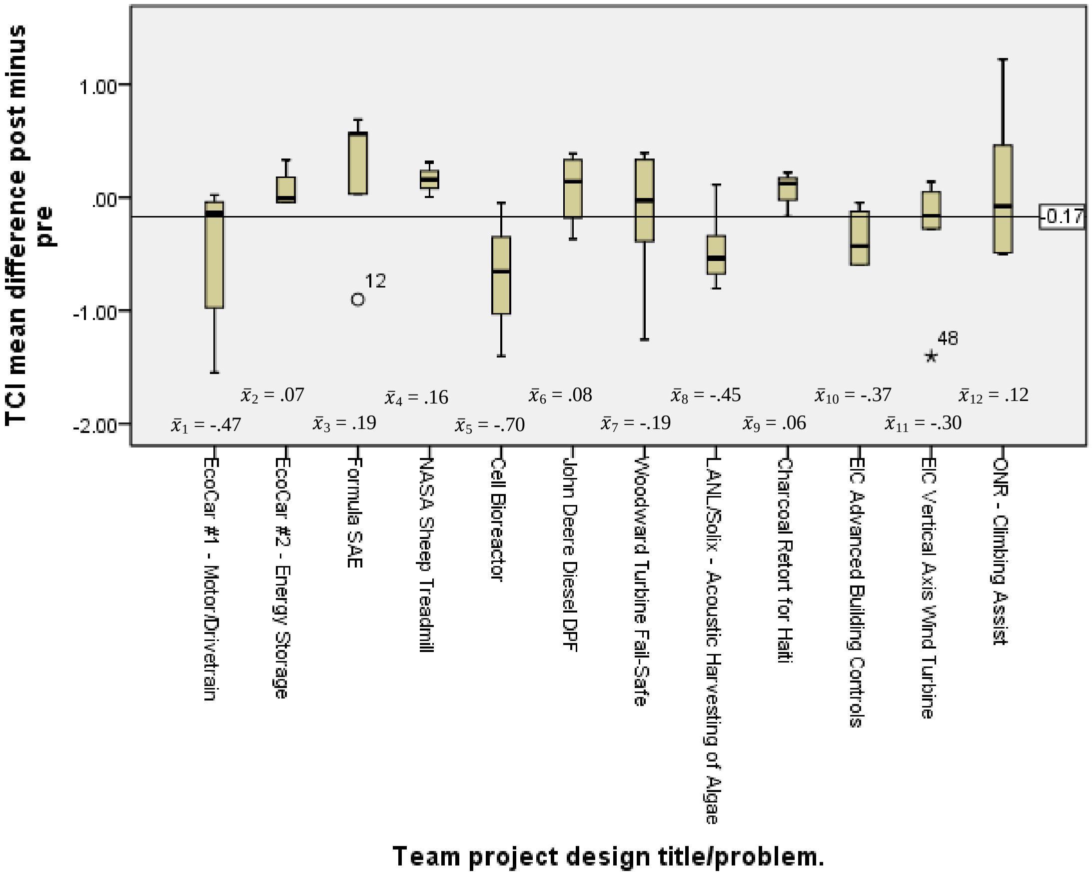


Figure 4.3. Comparative boxplot of the team interaction for each senior design team with group mean of -.17

Table 4.20 displays the pattern of the constructs measured in this study on the senior design outcome based on the group mean score on all four constructs. There were five teams with scores above the group mean on engineering GPA (*M* > .2.94). For the creativity level composite score, there were three teams below the TTCT group mean score (*M* < 106.74). The pre and posttest mean differences were used to represent the growth or decline of team interaction within each team. Six teams had positive scores based on the average mean differences of the TCI that could be interpreted as a positive change in team interaction. Five teams scored above the average score of 12 design teams ($M > 76.52$), where the total score for the senior design outcome was 95 points.

Only three design teams that had a high engineering knowledge score met the expectation of having a high product or design solution score or vice versa. The other eight design teams showed contrary results. For creativity, only two design teams met the expectation of having a high product score or vice versa. Five design teams met the possibility of positive/negative interaction impact on their senior design outcome score.

Overall, based on Table 4.20, there was only one design team (Formula SAE) that met the original hypothesis that design teams who score above average on creativity, engineering knowledge, and positive team interaction resulted in scoring above average on their design outcome score. Two design teams, including the John Deere DPF and Charcoal Retort for Haiti, were in contradiction of the original hypothesis: although they scored above average on all three main constructs, they scored below average on their design outcome. One design team (EcoCar – Motor/Drivetrain) scored below average on all three main constructs but scored above average on their design outcome.

Table 4.20

Engineering Knowledge, Creativity, Team Interaction and Senior Design Outcome Pattern (n=12)

Design Team	Engineering Knowledge (*M* = 2.94)	Creativity (*M* = 106.74)	Team Interaction (*M* = -.17)	Senior Design Outcome (*M* = 76.52)
T1	Below	Below	Below	Above
T2	Below	Above	Above	Below
T3	Above	Above	Above	Above
T4	Below	Below	Above	Above
T5	Above	Above	Below	Below
T6	Above	Above	Above	Below
T7	Below	Above	Below	Above
T8	Below	Above	Below	Below
T9	Above	Above	Above	Below
T10	Below	Above	Below	Above
T11	Above	Above	Below	Below
T12	Below	Below	Above	Below

To explore if there was a difference in terms of creativity, engineering knowledge, and team interaction between each senior design team, the one-way ANOVA was utilized. A two-tailed test of significance with an alpha of 0.05 was used to determine if there was any statistical difference between the design teams. The results indicated that there was a statistically significant difference between design teams on their team interaction, *F* (54) = 3.96, *p* = .001. There was no statistically significant difference between design teams for the other two constructs including creativity and engineering knowledge, *F* (54) = .63, *p* = .792, and *F* (54) = 1.36, *p* = .225, respectively. The one-way ANOVA results were supported by the boxplots shown in Figure 4.1, 4.2, and 4.3.

Table 4.21 summarizes the overall results of the correlation analysis between main constructs of the study including the TTCT creativity index, engineering knowledge, TCI team interaction, and product total score. Overall, there was no significant association found between constructs measured in this study with the senior design outcome. Due to limited number of teams in the study (*n* = 12), the researcher's interpretation of the findings do not suggest generalizing beyond the study sample.

Table 4.21

Intercorrelations for TTCT Creativity Index, Engineering Knowledge, TCI Team Interaction, and Senior Design Outcome Score (n = 12)

Construct	1.	2.	3.	4.	5.
1. TTCT Creativity Index	-	.129	-.239	.107	-.012
2. Engineering Knowledge		-	-.047	-.291	-.287
3. TCI Team Interaction (Average)			-	-.486	.073
4. TCI Team Interaction (Difference)				-	.106
5. Senior Design Outcome Score					-

Summary

The research questions central to this study have been answered through statistical analysis using IBM SPSS version 20. Descriptive statistics were utilized to describe the sample of the study in terms of their engineering GPA, creativity score, and team interaction score. The correlational analysis was executed to examine the relationship between the constructs of the study. At design team level, results from this research indicate that there was no statistically significant relationship between the creativity composite score and the design outcome. There was also no statistically significant relationship between the team interaction score and the design outcome. The team composite creativity score had no significant relationship with the interaction climate. The composite of team engineering knowledge had no significant relationship to the team interaction score. At the individual level, the correlation analysis indicated there was no statistically significant relationship between student engineering knowledge and the creativity score.

Exploratory data analysis (EDA) was used to assess the interaction of the main constructs on the engineering design outcome. The EDA results indicate that only one team met the hypothesis that a team scoring above average on engineering knowledge and creativity, and a positive team interaction climate would expect to score above average on their design outcome score. Two design teams scored above average on creativity and engineering knowledge, and positive team interaction climate score, yet scored below average on their design outcome, which went against the original hypothesis. One design team scored above average on their design outcome, but scored below average on the three main constructs of the study. The remaining eight design teams did not show any pattern of relationships among the three constructs of their design outcome. Although most of correlation analysis was not significant, it is important for the researcher to report the findings in a transparent manner rather than deceptive (S. E. Morgan, Reichert, & Harrison, 2002). A discussion, conclusions, and recommendations based on these findings follow in the next chapter.

CHAPTER 5: DISCUSSION AND CONCLUSION

"Our nation's long-term ability to succeed in exporting to the growing global marketplace hinges on the ability of today's students." - J. Willard Marriot, Jr. (2006)

Overview of the Study

Most students choose to enroll in an engineering program because they believe engineering involves solving real-life problems (Blicblau & Steiner, 1998) . The final year engineering projects or a capstone design course is one of the best platforms for students' to demonstrate their engineering knowledge, creativity, and teamwork ability not only for themselves but more importantly, for their future employer. The final year projects showcase is intended to demonstrate the engineering students' outcomes of:

1) mastery of a basic scientific principles underlying the engineering method
2) sound knowledge of the essentials of engineering science and practice
3) a thorough understanding of appropriate engineering methods and the ability to apply them with originality and resourcefulness
4) communication skills so that students can present their ideas clearly by verbal, written, and graphic means. (Blicblau & Steiner, 1998, p. 56)

Therefore, the purpose of this study is to explore the role and relationships between creativity, engineering knowledge, and team interaction on senior design outcomes. The discussion for the research questions is presented in the order in which the research questions were asked and listed under separate headings. The study's limitations, implications, and recommendations for future research will also be discussed in this chapter.

Instrumentation of the Study

There are three main instruments used in this study to assess engineering students' creativity, team interaction, and their senior design outcome. In this section, the researcher will discuss the findings related with the instruments including the findings on participants' engineering knowledge.

Engineering course grade point average (GPA) was used as a proxy to represent participants' engineering knowledge. The engineering course GPA was defined as the prerequisite courses that students need to complete with a minimum passing grade of C which include mathematics, chemistry, physics, and related mechanical engineering courses. The engineering GPA was computed for each student who volunteered to participate in the study. The GPA for each sub-discipline was also computed to examine the relationship between sub-GPAs and creativity. The analysis of the relationship between sub-GPAs indicated that there were significant relationships present. For the purpose of further analysis of the relationships between other main constructs in this study (i.e., creativity, team interaction, and senior design outcome), the researcher only used the engineering GPA to represent participants' knowledge level. The descriptive statistics indicated that the group mean (n = 88) engineering GPA was 2.94 with a standard deviation of .45. About 55% of the sample had engineering GPA scores above the group mean. Composite engineering knowledge for each team (n = 12) was computed by averaging the individual engineering GPAs according to the senior design team size. In terms of team engineering knowledge composite score difference, the results indicated that there was no statistically significant difference between the senior design teams.

The Torrance Tests of Creative Thinking (TTCT) Figural Form A measured five norm referenced assessments (i.e., fluency, originality, abstractness of titles, elaboration, and resistance to premature closure). The average standard score and the creativity index were utilized to capture student creativity. Each area was evaluated looking at the senior engineering student creativity performance. The analysis of relationships indicated significant relationships were found between the five norms referenced in the TTCT. For the purpose of further analysis of relationships between main constructs in this study (i.e., engineering knowledge, team interaction, and senior design outcome), the researcher used the creativity index score to represent participants' creativity level. The group mean score for the TTCT creativity index was reported to be 106.74 with a standard deviation of 12.17. About 45% of the sample scored above the group mean on the TTCT creativity index. The team composite creativity index was computed by averaging the individual creativity index according to the senior design team size. In terms of team creativity composite score difference, the results indicated that there was no statistically significant difference found between the senior design teams.

The 36 item Team Climate Inventory (TCI) was used to gathered data related to team interaction. There were five factors measured in the TCI including vision, participation safety, support for innovation, task orientation, and interaction frequency. The TCI was administered twice during the period of the study to detect growth or decline in team interaction. Each factor was evaluated looking at the senior engineering students' individual perceptions about their design team. The analysis of relationships at pretest indicated that there was a significant relationship between TCI factors. The reliability of the TCI was examined and the results showed that the TCI at pretest has reliability ranging from .80 to .93, which is considered acceptable (G. A. Morgan, et al., 2004). However the test retest reliability score of .61 was slightly below the acceptance limit of .70. For the purpose of further analysis of relationships between other main constructs in the study (i.e., creativity engineering knowledge, and senior design outcome), the researcher used the TCI pre and post mean difference to represent positive or negative climate in team interaction. The descriptive statistics of the TCI indicated that the group mean score rating was between *agree/great* and *strongly agree/to a very great extent* on their team vision, participation safety, support for innovation, task orientation, and interaction frequency. The descriptive statistics also indicated that six out of 12 design teams had a positive climate in their team interaction.

The senior design outcome judging criteria was adapted from the Student Product Assessment Form (SPAF) developed by Reis (1981). The adapted instrument was divided into two main sections including Technical Approach and Final Design Solution, and the Overall Assessment. The summation of these two sections was referred to as the Senior Design Outcome Score. The adapted instrument was reviewed for content validity by experts in both content and measurement areas. An hour training session for raters was conducted on the same day of the senior design showcase in spring 2012 semester. Fourteen raters consisting of 11 professional engineers and three graduate students volunteered to participate and be the senior design judges on that day. The raters were divided into three teams consisting of four to five raters each, which were then assigned to evaluate four senior design projects. The rater demographics were discussed in Chapter 4. The analysis of relationships showed there was a significant relationship between the two main sections of the adapted instrument. The descriptive statistics indicated that the group mean score on design outcome was 76.52 of 96 possible points. The interater reliability of the adapted instrument based on five raters was reported to range from .55 to .68.

The following headings will discuss details about the research findings. Due to a limited sample size, it is important to acknowledge that the discussion of the findings is only true in this research setting and does not reflect nor can it be generalized to a bigger population.

Relationship Between Creativity and Senior Design Outcome

Following a review of the literature, the researcher discussed the notion that creativity and engineering design share a common process especially at the beginning stage of the design phase. A psychometric approach was utilized to capture team creativity and the senior design outcome. This approach considered the most popular and widely used in examining the relationship between creativity and engineering design outcome. Lumsdaine et al. (1999) argue that elements of creativity including the originality and the knack for elaboration should contribute to team effectiveness and productivity to elicit a better design. However, the results in this study show that there was no significant relationship between creativity and the design outcome. In other words, creative team did not have any effect or guarantee that a team would produce a better design or solution.

Relationship Between Team Interaction and Senior Design Outcome

Human resource professionals in the engineering industry are seeking not only creators or inventors, but individuals who can work in a collaborative setting. Collaboration has powerful effects on individual learning including increasing students' social skills competency such as conflict resolution and helping behavior (Ginsburg-

Block, Rohrbeck, & Fantuzzo, 2006). In addition, a positive social climate in the teamwork environment and the feeling of security among team members tend to promote positive emotional states and positive outcomes (James, Clark, & Cropanzano, 1999).

Literature has shown that engineers solve engineering problems in teams. However, the results from this study indicate that there is no significant relationship between design team interaction and senior design outcome. In other words, the social climate in the design team had no effect on the students’ senior design outcome. Although this study did not support the literature, student engagement in creative processes has been suggested as a critical activity needed for team success (Gilson & Shalley, 2004).

Relationship Between Creativity and Team Interaction

Given the dynamic environment in which many industries operate, it is best to have teams that are willing to explore possibilities (i.e., try different things, explore new work process), and otherwise look to improve the manner in which work gets accomplished. The results from this study showed no significant relationship between the team composite creativity score and team interaction score. As a result, the speculation could be made that it is not necessary for a creative team to interact or communicate well among individuals in their teams. This finding may not fit with the findings of Lumsdaine et al. (1999) regarding creative team characteristics as shown in Table 6 in Chapter 3, in which one of the characteristics needed for a creative team was to have skills for dialogue and candid debate with customers and peers.

Relationship Between Engineering Knowledge and Creativity

There were numerous studies that examined the relationship between knowledge and creativity since it has had a long history in psychology (Weisberg, 1999). Weisberg (1999) stated, “the relationship between knowledge and creativity is one of the tensions that has a long history in psychology” (p. 226) and there are limited studies that have examined the relationship between knowledge and creativity within the engineering field.

It has been shown in previous research by Cicirelli (1965) and Gluskinos (1971) that there was no significant relationship between student creativity and academic achievement. Cicirelli (1965) used three different measures to gather academic achievement including the California Arithmetic Test, California Language Test, and the Gates Basic Reading Test. Gluskinos (1971) used overall students’ grade point average as an academic achievement indicator. Despite not detecting any relationship between creativity and knowledge, Gluskinos (1971) suggested using other grades to represent student knowledge. Implementing Gluskinos’ (1971) suggestion and using the engineering GPA instead of overall GPA, there was no relationship between engineering knowledge measured by engineering GPA and creativity measured by the TTCT in this study. The results also showed that there was no evidence of a relationship between engineering sub-disciplines GPAs including mathematics, science (chemistry and physics), and basic engineering science with creativity.

Letter grades are considered the best way of representing student scholastic achievement and providing information to students, teachers, employers, and other external audiences as to whether students have mastered the course material (Bursuck & Munk, 1998; Calhoun & Beattie, 1984; Immerwahr, 2010; Oliver, 1960; Withington, 1944). However, the debate on using GPA to represent students' level of knowledge has a long history in psychology research (Goldman & Slaughter, 1976). The GPA consists of composite variables of nonequivalent components. Goldman and Slaughter (1976) argue that the GPA rises from the different grading standards in different types of college classes. Perhaps, in this study, the engineering GPA is not the best indicator to represent the student domain-specific knowledge. Another speculation that can be made and argued based on this study is that level of knowledge does not necessarily represent or relate to creativity level. Kemper and Sanders (2001) stated that most industries expect their engineers to be creative and therefore, despite the insignificant findings on the relationship between engineering knowledge and creativity, it has been suggested in the literature that creativity should and could be enhanced throughout the engineering curriculum (i.e., D. H. Cropley & Cropley, 2000; Lai & Viering, 2012). The remaining and still lingering question is how and to what extent we might be able to measure such gains in student design creativity.

Relationships Between Engineering Knowledge and Team Interaction

One of the purposes in solving any engineering problem in teams is to share knowledge. However, it must be recognized that in any situation working in teams, an individual team member thinks and behaves in preferred ways that are unique to that person (Haik, 2003). For example, in solving a given engineering design problem, one team member may carefully analyze that problem before making a rational and logical decision based on the available data. Another team member may see the same problem in a bigger context and look for several possible solutions. Another team member will use a very detailed, cautious, step-by-step procedure to solve the problem.

In this study, the researcher did not find any significant relationship between engineering knowledge and team interaction. The researcher can suggest that the level of engineering knowledge has no effect on how the design team interacts based on the insignificant correlation found between engineering GPA and team interaction mean difference score. Perhaps the engineering GPA as determined in this study has little relationship to how an engineering design team interacts while engaging in a design problem solution.

Interaction Among Creativity, Engineering Knowledge, and Team Interaction on Engineering Design Outcome

Most of the engineering design textbooks emphasized the importance of having sufficient engineering knowledge that can be applied in the designing process. The knowledge includes and is not limited to selection of the materials, the manufacturing process, ergonomics, etc. Along with the engineering knowledge, the engineering designer is also expected to be creative, innovative, and willing to work in a team environment (Haik, 2003; Lumsdaine, et al., 1999; Madsen, et al., 2004). It is interesting to examine how these three important variables in engineering design interact and therefore impact the overall design outcome or solution.

There is not much that can be discussed about the findings due to the small numbers of design teams (*n* = 12) who volunteered to participate in this study. However, based on the exploratory data analysis conducted to discern the pattern of the results across the main three constructs, one design team met the hypothesis that creative teams with high engineering knowledge and a positive team interaction climate will produce a better outcome. Surprisingly, two design teams had the opposite outcome whereby even though they scored above group average in these three variables, the design solution or outcome was below the group average. Therefore, further investigation needs to be done to explore this finding and will be discussed in the following section.

Implications for Action

For decades, manufacturing industries have complained that our fresh engineering graduates fall short on practical skills that would make them more productive in the real practical world (Masi, 1995, p. 44). The recent publication by Partnership of 21st Century (P21) (2011) has created a comprehensive framework for conceptualizing different types of skills important for higher education and the workforce. For example, learning and innovation skills that include creativity and innovation, and communication and collaboration skills need to be enhanced in the college classroom. Therefore, it is important for educational institutions to expose and provide experiences for their engineering students in real world problems through not only their current knowledge but also through innovation and collaborative work with their peers and professors. In this section, the researcher proposes actions for four categories including institutions, engineering professors or instructors, researchers, and industry.

Education Institutions

As a formal training institution that produces future engineers, the higher education institution should ask itself whether it prepared graduates with job related skills at the appropriate level. Skills such as creative thinking, communication, and ability to work in a team environment are considered to be important skills for young engineers to achieve success in their future careers. In engineering education, although creativity could be enhanced and probably understood better by both instructors and students, problems in understanding the creative process itself still exist (LaChapelle, 1983).

Although most of the results did not indicate significant findings, there is a need for educational institutions to understand and be able to determine not only its graduates' academic achievement but other job related skills including creativity and teamwork while they are in college. Baillie and Walker (1998) purport that,

> to prepare engineering students for a changing future and to help them develop their own capacity for independent innovative thought and creative problem solving, we are faced with the need to explore ways of fostering creativity in students within engineering programs (p. 35).

In the recent publication by Lai and Viering (2012), they stated "21st century skills" and "college and career readiness" have become a concern and need to be emphasized in curriculum and instruction in higher education. Along with this concern, an appropriate assessment on a large scale is needed to measure students' competency in these skills. Two of the skills being investigated in this study, creativity and teamwork, should become primary educational goals to produce creative and collaborative engineers. To achieve this goal, senior design showcase has become popular and widely used by many engineering schools not only to assess students' performance (i.e., creativity and teamwork) but also to promote their students work to the public and industry. Organizing the senior design showcase every academic year was a big effort by an educational institution to promote their students' work not just to the public but also to their potential employers. The senior design showcase helped students to communicate and share with their peers, professors, and industries about their work.

Engineering Professor/Instructor

As senior design capstone course professors or instructors, one of the main tasks is to help prepare students for a career in engineering (Blicblau & Steiner, 1998; Goldberg, 2011). The senior design capstone course and other engineering curriculum should help students' technical, interpersonal, and communication skills and provide them with the broad knowledge base they will need for successful careers.

Students should understand that in many companies, engineers do not get to choose the projects on which they will work. New engineers may work on projects that may not be as interesting as others. They also need to understand and recognize that engineering resources are assigned to projects that are expected to be the most profitable and generate the highest return on investment. This leads to the need for young engineers to prove themselves and demonstrate project management (i.e., teamwork) and design skills (i.e., engineering knowledge, creativity) before they are assigned to more desirable, high-profile projects (Goldberg, 2011).

Psychologists such as Guilford (1950) have long maintained the significance of fostering creativity development in order to prepare young generations for a changing future. However, Lai and Viering (2012) purport that educators still separate creativity from mainstream curricula. As an engineering professor, creativity and teamwork should be enhanced during any engineering course. Research has shown that teams that were more engaged in creative processes had members who socialized more frequently (i.e.,Gilson & Shalley, 2004). Gilson and Shalley (2004) stated that socializing could foster creativity by allowing “freer flow of ideas, more brainstorming, and less threatening work environment” (p. 466). As the engineering curriculum progresses, students should be engaged in design activity from the very beginning because the creative process comes not only from the five elements of creativity (i.e., fluency, originality, abstractness of titles, elaboration, and resistance to premature closure) as measured by the Torrance’s test, but also by experience in different problem contexts. In other words, creativity also comes with experience. For example, in freshman and sophomore engineering courses, students should be engaged in small, well-defined design problems that can be accomplished in a short period of time (i.e., two to three weeks). This will help engineering students to understand that as they go through the curriculum, the design problems become more complex, and the challenges get longer. Students will gain not only in their problem solving skills, but also can be expected to gain experience with team planning, time management, and team interaction.

However, it must be acknowledge that engineering design also takes on multiple characteristics. For example, in the case of routine design, many design projects do not allow for creativity. If the design task is to design to a specification, creativity will not be observed perhaps in the product outcome because it was specified, yet creativity may be in the process. In other words, time compression could be considered a creative endeavor, but it is a process endeavor. On the other hand, some design problems allow for multiple degrees of freedom and multiple free choice solutions for the product outcome. In this case, function maybe specified but not form. This form of design creativity allows for both process and product development creativity.

One of the primary goals of design education is "to transfer knowledge of solving design problems in such a way as to prepare students for their development from novices to design experts" (Christiaans & Venselaar, 2005, p. 232). To meet this primary goal, it has been suggested by Davis, Gentili, Trevisan, and Calkins (2002) that the faculty who teach engineering design must have the following four abilities:

a) understand teamwork, engineering design process, and effective engineering design communication skills;
b) define engineering design outcomes desired at different points in the curricula;
c) employ pedagogy that develop desired student capabilities in engineering design; and
d) measure student achievement of engineering design outcomes using reliable and valid assessment tools (p. 211)

Engineering design outcome assessment tools have not yet matured, become well-established, and accepted widely by engineering educators due to the complex nature of the design process itself (Davis, et al., 2002). However, continuous work should be enhanced to develop valid and reliable assessment rubrics and scales that provide feedback for improvement especially in engineering design education to meet and support ABET accreditation outcomes of engineering programs.

Engineering Education Researcher

Educational researchers played a major role in investigating the connections among creativity, knowledge, and team interaction on engineering design outcome. From selecting the participants who represent specific populations, adapting and/or developing questionnaires or assessment instruments, and coordinating the design professional's judgments of projects, each to adds rigor in the study design. There are multiple approaches that can be used by researchers to assess each of the constructs including self-report surveys (to assess participants' skills, attitude, and dispositions), global rating scales (to capture participants' skills completed by others such as peers, educators, etc.), standardized assessments using multiple-choice items or open-ended format, and observational measures to capture students' specific behaviors relevant to a specific skills (Lai & Viering, 2012).

It is important to acknowledge that as a researcher, the most contentious issue concerns how to study creativity. In the review of the literature, this researcher has explored multiple approaches that can be used by researchers to discover creativity. In this study, the researcher used one of the widely used approaches, which is the psychometric approach proposed originally by Guilford (1950). The psychometric approach viewed creativity as a mental trait that can be quantified by appropriate measurement tools. It will be fruitful if we can examine the knowledge growth, as well as other important job related skills including creativity and the ability to work in teams at regular intervals as engineering students progress in college.

Industry

Engineering education is constantly being reviewed, changed, and improved (Kemper & Sanders, 2001). Industries play a major role in this improvement since the engineering graduate will serve them in the future. Therefore industry's contribution is to ensure the quality of engineering graduates not only on their academic achievement, but also in other job related skills. In this study, the cooperation from well-known corporations including Intel Corporation, Microsoft Corporation, Agilent Technologies, and Covidien by providing their experts to evaluate senior design projects was very much appreciated. Continuous support and input from them and other industries to engage in research related with engineering education is needed to improve the content and the experience of undergraduates in higher education.

In summary, we need to acknowledge that the job related skills including creativity, team interaction, and engineering design activity can be reliably assessed (Anderson & West, 1998; Davis, et al., 2002; Kim, 2006). Waks and Merdler (2003) argue that “creativity in engineering design had become an economic necessity and not merely the privilege of unique individuals” (p. 101). Yet, it is our hope that the present investigation has contributed to current understanding of the relationship between knowledge, creativity, and team interaction especially in the mechanical engineering field. Based on the findings, although there was a correlation within the creativity test constructs as well as within the engineering knowledge and team interaction survey, there was no statistically significant relationship between these three constructs in engineering design. The study has limited sample sizes and focuses only on one group. Therefore an effort should be made by educational institutions, engineering professors, together with educational researchers to replicate and expand this study to other engineering fields and/or at other institutions before any further claim to generalizability for these results can be made.

Measurement Dilemma and Challenges

Educational assessment is perhaps the hardest science of all especially when focused on assessing student performance (Stiggins, 1991). Authentic assessment methods such as portfolios, process evaluation, evaluations of products and student artifacts, science/engineering fairs, etc. have become common in school cultures. These type of performance assessment are based on the professional judgment that comes from experts including educators and professionals working in specific fields. In this study, the researcher attempted to assess final year engineering students' performance on their final design outcome based on the creativity level, application of knowledge, and team climate.

There were significant measurement dilemmas and challenges in this study that might have influenced the research findings. The purpose of this section is to discuss some of the dilemma and challenges of measurement that influenced this study. The discussion will be divided into two sections including the current study and the missing elements of the study.

Current study. The first issue relates to the possibility that the engineering GPA may not be an appropriate measure to represent student level of knowledge due to some reasons that have been discussed in the previous section. The argument on using GPA to represent student level of knowledge has a long history in psychology research (Goldman & Slaughter, 1976). Goldman and Slaughter (1976) argue that the GPA consists of composite variables of nonequivalent components and rises from the different grading standards in different types of college classes.

Second, in the current study, two well established instruments were utilized to capture student creativity and team interaction score. The Torrance Tests of Creative Thinking (TTCT) Figural Form A was used to capture engineering student creativity levels. Although the TTCT was professionally scored by Scholastic Testing Service (STS), the researcher did not conduct a reliability analysis on the TTCT due to limited information on the evaluation process received from STS. This included the number of raters who evaluated the test and TTCT score from each rater. This information would be helpful for the researcher to examine interrater reliability of the TTCT in this study. The adapted 36 item Team Climate Inventory (TCI) was administered twice to capture growth or decline in design team interaction. Since the number of the students who completed questionnaires in pre and posttest is small (*n* = 55), the researcher did not conduct the exploratory factor analysis (EFA) to determine the number of factors that emerged from the adapted TCI. Although the Cronbach's Alpha for the adapted instrument at pretest was reported to be acceptable, the EFA would help the researcher to refine the adapted TCI measures, evaluate construct validity, and maybe in the future test the hypotheses.

The third issue was related to the senior design Judging Criteria rubric. It was reported in Chapter 4 that all of the professional raters rated the rubric as "good" to measure the design outcome. However, the adapted judging criteria rubric had interrater reliability ranging from .55 to .68, which may not be sufficient. The low reliability coefficient indicates that the instrument may not be sensitive enough to capture the engineering design outcome including the design process that each team went through in completing the project and the overall quality and/or originality of the design outcome.

Methodological elements for future consideration. Due to limited time in completing this study, the researcher acknowledges, there was no attempt to conduct observations of teamwork performance that could be useful to detect students' cognitive behavior while they are solving the design problem. Perhaps there was research conducted in the past that tried to investigate the relationship of the variables within the engineering design process including the one that the researcher used in this study (measuring the relationship between creativity, engineering knowledge, and team interaction on engineering design solutions). However, what actually happened in the design team while they were solving the problem is still questionable unless we see and experience it for ourselves. Therefore, the researcher's recommendation is to conduct or expand this study and include an observation protocol to detect the specific behaviors of the engineering design team that could relate to the outcomes or solutions to the problem.

Team development is another element that may be useful to be examine. In the current study, the researcher only administered the TCI once a semester and before the engineering design showcase. A question still remains: what if the researcher collected a third TCI after the showcase, after the participants were evaluated and scored by raters, either professional engineers or faculty members? Is there any possibility that the team interaction ratings would continue to decline, or would growth be observed based on the feedback that each team received from the raters? It is a difficult decision to make by researchers, to determine when the right time or moment is to distribute the team interaction questionnaire, since different teams tend to have different levels of momentum in their working progress. However, the researcher's suggestion is to expand this study and have team interaction measured multiple times to detect design team development.

The design process takes time to complete and may involve different steps and phases along it way. To avoid being disorganized, it has been stressed that engineering designers keep design notebooks, where they can record every detail of their projects. In the senior design capstone course, each student is required to maintain a design notebook as a complete documentation history of a project's details. The content of the design notebook may include, but is not limited, to related calculation, brainstorming sketches, information gathered through research, cost estimation for the entire project, etc. Figure 5.1 shows how one of the famous inventors, Leonardo da Vinci’s, notebook on creating water wheels and the Archimedes pump (Science Buddies, 2012).

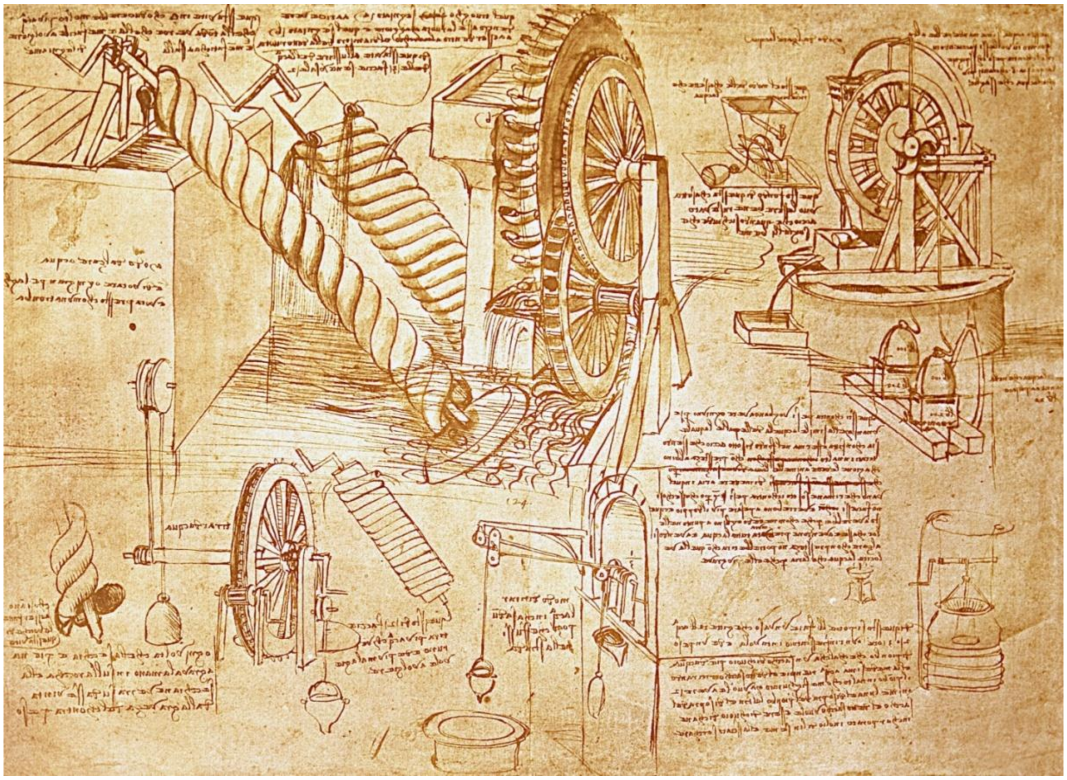
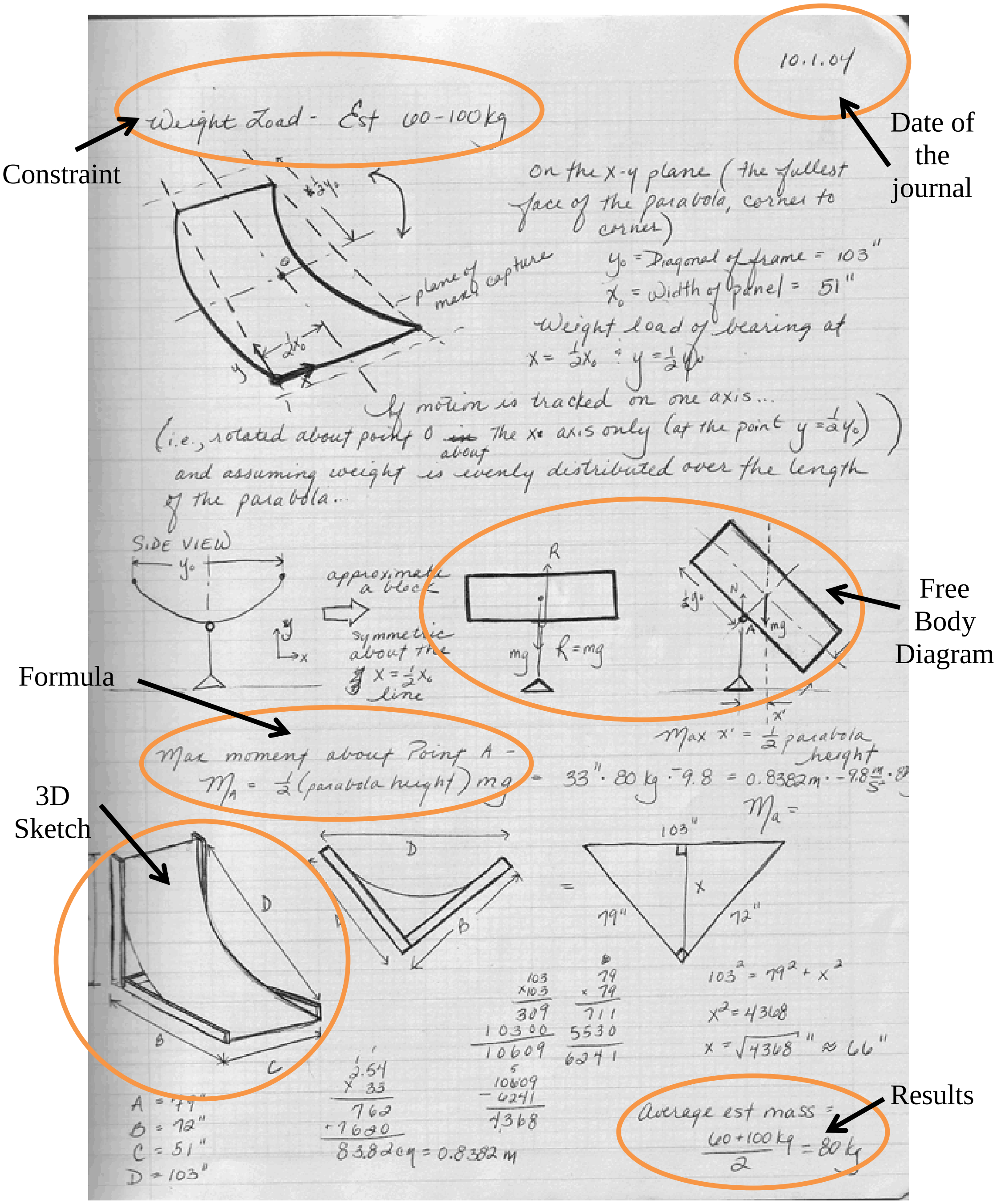


Figure 5.1. Leonardo daVinci's notebook shows his work on water wheels and Archimedes pumps. Retrieved April 12, 2012, from http://www.sciencebuddies.org /engineering-design-process/SciF_EngrDesignGuide_Notebook_Leonardo_Codex Atlanticus.jpg

The design notebook should be utilized to document all individual student work and contributions toward a team project. A notebook is considered a working document and it must provide a comprehensive trail of descriptive evidence for each individual student's product development effort. One of the advantages of keeping a good design notebook is that at the end of the project, when someone reviews the design notebook, he or she should be able to understand fully how the designer arrived at his/her solution. Figure 5.2 shows a sample of the engineering notebook that indicates some of the necessary content including the date of the journal created, constraint, sketches, applied knowledge, and calculation (Massachusetts Institute of Technology, 2011).



10.1.04

Weight Load - Est 60-100kg

On the x-y plane (the fullest face of the parabola, corner to corner)

y_0 = Diagonal of frame = 103"

x_0 = Width of panel = 51"

Weight load of bearing at

$x = \frac{1}{2}x_0$; $y = \frac{1}{2}y_0$

If motion is tracked on one axis... (i.e., rotated about point 0 ~~in~~ about the x axis only (at the point $y = \frac{1}{2}y_0$)) and assuming weight is evenly distributed over the length of the parabola...

Max moment about Point A -

$M_A = \frac{1}{2}(\text{parabola height})\, mg = 33'' \cdot 80\text{ kg} \cdot {-9.8} = 0.8382\text{m} \cdot {-9.8}\frac{m}{s^2} \cdot 8$

Max $x' = \frac{1}{2}$ parabola height

$M_A =$

A = 79"
B = 72"
C = 51"
D = 103"

$$\begin{array}{r} 2.54 \\ \times\ 33 \\ \hline 762 \\ +7620 \\ \hline 83.82\text{ cm} \end{array} = 0.8382\text{ m}$$

$$\begin{array}{r} 103 \\ \times 103 \\ \hline 309 \\ 10300 \\ \hline 10609 \end{array} \qquad \begin{array}{r} 79 \\ \times\ 79 \\ \hline 711 \\ 5530 \\ \hline 6241 \end{array} \qquad \begin{array}{r} 10609 \\ -\ 6241 \\ \hline 4368 \end{array}$$

$103^2 = 79^2 + x^2$

$x^2 = 4368$

$x = \sqrt{4368}'' \approx 66''$

Average est mass = $\frac{60 + 100\text{ kg}}{2} = 80\text{ kg}$

Figure 5.2. A sample of engineering design notebook page that indicate date, constraint, sketches and calculations involved in completing a specific project. Retrieved April 12, 2012, from http://web.mit.edu/2.009/www/assignments/DesignNotebook.html

The content analysis on the engineering design notebook is helpful to capture work in progress during the project period. It can be used to capture how a student applied his/her creative and critical thinking, engineering knowledge, and how a student communicates his/her idea with other team members in completing the project. It would be interesting to examine how well students perform in the brainstorming process (i.e., how many ideas generated), the application of engineering principles (i.e., mechanics, free body diagram (FBD)), as well as number of design iterations that were involved in completing the project.

Despite the dilemmas and challenges discussed above, an attempt to improve the study of engineering product design must continue to achieve better understandings of design results. The researcher will discuss the recommendations for research in the following section.

Recommendations for Research

There are some areas for future research that logically present themselves based on the results of this study. The disconfirming results suggest a number of research areas that would serve to increase the understanding of the relationship between creativity, engineering knowledge, team interaction, and how these three factors impact the senior design outcome. The main area that can be improved to have more robust and better results is to increase the sample size and scope of the population. The sample size is an important feature of any empirical study that attempts to make inferences or speculations about a population from a sample. By increasing the sample size, there is a better chance for the data to be normally distributed and better serve to represent the population. Therefore, the researcher has a plan to replicate the study with Malaysian engineering undergraduate students at a local university.

Based on the literature review, the researcher has presented how loosely creativity has been defined and how individuals perceive creativity differently. This leads to the argument that perhaps there are no standard instruments that can be used to truly determine human creativity levels (Afolabi, Dionne, & III, 2006). One of the limitations of the TTCT is that the test is based on “best guesses” or approximations of what creativity may actually be. Another limitation that needs to be considered is the test format (a paper and pencil test), which some researchers such as Sternberg and Lubart (1999) find to be insufficient to measure creativity. Despite all the TTCT limitations, based on the literature, the researcher still believes that the TTCT is valuable and useful to examine individual creative potential since it is well developed and being referred to as a national standardized instrument to measure students’ creativity. As far as the researcher is concerned through his initial investigation and search of scientific literature (i.e., EBSCO, Mental Measurement Yearbook^{TM}, Google Scholar), no such research has been done using the TTCT to capture engineering students’ creativity at college level. Therefore, further exploration with a larger sample size is needed to support the researcher’s belief that the TTCT can be utilized to assess engineering students’ creativity levels. It will also be interesting to examine the difference between groups including different engineering fields (i.e., civil, electrical engineering) as well as their gender on creativity performance.

There are multiple approaches in assessing teamwork skills. Parker and Salas (1992) proposed six principles for team performance measurement including:

1. For understanding teamwork, there is nothing more practical than a good theory
2. What you see may not be what you get
3. There is no escaping observation
4. Applications, applications, applications

5. Judges and measures must be reliable
6. Validation for practice and theory (p. 474)

Due to limited time in completing this study, the researcher acknowledges that in this study, there was no attempt to conduct a practical observation in measuring teamwork performance that could be useful to detect students' cognitive behavior while they are solving the design problem in teams. Perhaps there was plentiful research in the past that tried to investigate the relationship of the variables within the engineering design process including the one that the researcher used in this study (measuring the relationship between creativity, engineering knowledge, and team interaction on engineering design solutions). However, what actually happened in the design team while they were solving the problem is still questionable unless we see and experience it for ourselves. Therefore, it is recommended by the researcher to conduct or expand this study and include the observation protocol in order to detect the specific behavior of the engineering design team that could relate to the outcomes or solutions of the problem. In addition to the observation protocol, it would be interesting to examine design team development by distributing the team interaction questionnaire multiple times (instead of twice in this study) to detect and reconfirm either decline or growth of ratings in each design team climate across time.

It will be fruitful if researcher can examine engineering design notebook content for individual student. In the earlier section, the researcher has discussed the engineering design notebook content that may have information that relates to student creativity, his/her engineering knowledge, series of discussions, and decisions that the team had made to complete the project. The content analysis is used to detect the presence of certain words, concepts, themes, characters, or sentences within texts or sets of texts and to quantify this presence in an objective way. Therefore, the researcher recommendation is to expand this study and include the content analysis on the engineering design notebook to detect the specific content (i.e., ideas, sketches, calculation, discussion, etc.) that can be relate to the final design solutions.

There is room for improvement for the judging criteria or evaluation rubric used in this study. This was the first time the researcher executed the adapted senior design judging criteria or evaluation rubric without conducting a pilot test. Therefore, the researcher would suggest the adapted instrument be tested with a larger sample size and variety of raters' background (i.e., professional engineers, educators, potential client, etc.) to establish the reliability of the instrument as well as its items.

In addition to all the recommendations discussed above, a more scientific methodology would increase the understanding of the nature of the correlation between the constructs in this study. The use of a control group and experimental group in future studies would help to examine the differences between the groups instead of just correlations. The intervention may include, but not limited to, creative thinking, leadership, decision making courses, etc. that theoretically would affect individual or team progress/development in solving a specific engineering design problem. A longitudinal study would also be beneficial to the institution to examine their graduates creativity and teamwork performance while they are in college. This might help the researcher in engineering education to answer whether the current college engineering curriculum has made any significant contribution to students' creativity and ability to work in teams as well as whether or not creativity and teamwork was enhanced across curriculum at college level. Since most professors in engineering education and engineering students believe that creativity, knowledge, and teamwork are important, the question of whether the college or academic institution is effective in preparing its graduates to be more creative and able to work in a team environment to solve engineering problems in the future still remains to be answered.

The Remaining Questions

There are some remaining questions that cannot be answered through this study. This includes whether the Torrance Tests of Creative Thinking (TTCT) or its constructs really apply in an engineering context. Although it has been tested in other fields such as psychology and art, the researcher still has concerns whether the TTCT is applicable in the field of engineering to detect engineering student creativity. TTCT constructs such as resistance to premature closure may have a connection with the engineering student persistence in solving engineering problems. However, other constructs, such as abstractness of titles, are still questionable. It remains to be seen whether or not the TTCT constructs can be applied to or enhanced in engineering education.

The second question is since the literature supports that the engineering design evaluation rubric is not well established, can the Judging Criteria rubric used in this study detect creative or innovative elements in the product outcome? Further exploration, adaptation, and investigation are needed to examine both the content and measurement validity and reliability of the Judging Criteria rubric before any claim can be made to answer this question.

The third question relates to whether the researcher is measuring the right constructs in this study. Although creativity, knowledge, and teamwork are important elements in engineering design and desired by most industries, are these three factors the most desirable that contribute to engineering design success? And if they are the most desirable, which factors significantly provide higher impact on the design outcome?

In addition to the methodological questions discussed above, the researcher collected information on student skills and experience, and interests that were not included in this analysis. It may be of interest to examine this data and see if there are any relationships among participant skills, experience, and interests with the four major constructs of this study (i.e., creativity, engineering knowledge, teamwork, and senior design outcome). The exploratory analysis was not conducted because this data was not directly associated with the research question of this study. Therefore, it is the researcher's goal to execute future analysis in examining any correlation of the additional demographic data with the four major factors in this study. The results and findings from the analysis will be used by the researcher for future publication.

Conclusions

Literature on creativity, team interaction, and engineering design is common and has its own field perspective; therefore, the amount of literature on the related topic is huge. Despite disagreement in the literature, an attempt should be made to explore and investigate the connection between creativity, knowledge, and team interaction, and how these three individual constructs interact/relate and impact the design outcome in engineering education. A better understanding on the interaction of these three constructs would help engineering educators to design and establish a better curriculum for our future engineering student candidates. This study will, perhaps, be a good start for researchers in engineering education to explore the relationships between other job related skills and student achievement.

Concluding Remarks

It was a long journey for the researcher to complete this study. There were some issues that the researcher had to face throughout the study; most of them relating to the data collection process. Since the researcher conducted the research outside of his normal culture or environment, he gained a great deal of experience with the American education and organization environment, especially at the college level. Getting engaged with the American education system was a great experience he hopes to share with other colleagues and students in Malaysia.

The researcher hopes that this research provides some insight and expands the literature on engineering education. At the same time, more research needs to be done to fully understand the connection of three related constructs (creativity, engineering knowledge, and team interaction) and how it exists in the mind and is developed in engineering students over time. As a researcher and engineering educator, although the results of this research did not match his expectations, he will still continue to encourage his future students to develop their creativity, teamwork, and communication skills within the framework of the engineering profession.

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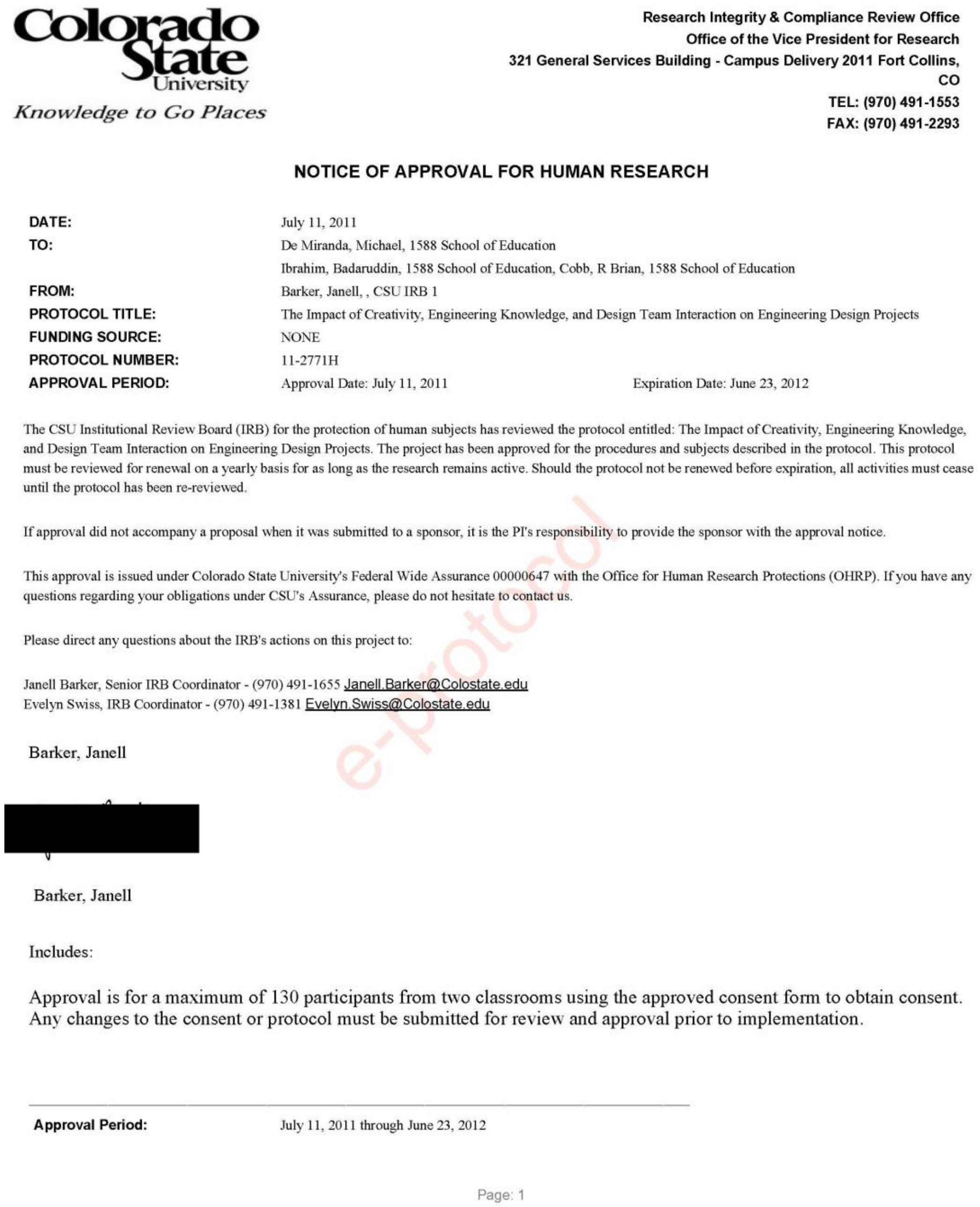
APPENDIX A. MECH486A/B 2011/2012 PROJECT LIST

Exploring the Relationships Among Creativity, Engineering Knowledge, and Design Team Interaction on Engineering Design Projects

Mechanical engineering senior design project involved in this study:

1. **EcoCar #1 - Motor/Drivetrain**
2. **EcoCar #2 - Energy Storage**
3. **Formula SAE**
4. **NASA Sheep Treadmill**
5. **Cell Bioreactor**
6. **John Deere Diesel DPF**
7. **Woodward Turbine Fail-safe**
8. **LANL/Solix - Acoustic Harvesting of Algae**
9. **Charcoal Retort for Haiti**
10. **EIC Advance Building Controls**
11. **EIC Vertical Axis Wind Turbine**
12. **ONR - Climbing Assist**

APPENDIX B. COLORADO STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL



Colorado State University
Knowledge to Go Places

Research Integrity & Compliance Review Office
Office of the Vice President for Research
321 General Services Building - Campus Delivery 2011 Fort Collins, CO
TEL: (970) 491-1553
FAX: (970) 491-2293

NOTICE OF APPROVAL FOR HUMAN RESEARCH

DATE:	July 11, 2011
TO:	De Miranda, Michael, 1588 School of Education Ibrahim, Badaruddin, 1588 School of Education, Cobb, R Brian, 1588 School of Education
FROM:	Barker, Janell, , CSU IRB 1
PROTOCOL TITLE:	The Impact of Creativity, Engineering Knowledge, and Design Team Interaction on Engineering Design Projects
FUNDING SOURCE:	NONE
PROTOCOL NUMBER:	11-2771H
APPROVAL PERIOD:	Approval Date: July 11, 2011 Expiration Date: June 23, 2012

The CSU Institutional Review Board (IRB) for the protection of human subjects has reviewed the protocol entitled: The Impact of Creativity, Engineering Knowledge, and Design Team Interaction on Engineering Design Projects. The project has been approved for the procedures and subjects described in the protocol. This protocol must be reviewed for renewal on a yearly basis for as long as the research remains active. Should the protocol not be renewed before expiration, all activities must cease until the protocol has been re-reviewed.

If approval did not accompany a proposal when it was submitted to a sponsor, it is the PI's responsibility to provide the sponsor with the approval notice.

This approval is issued under Colorado State University's Federal Wide Assurance 00000647 with the Office for Human Research Protections (OHRP). If you have any questions regarding your obligations under CSU's Assurance, please do not hesitate to contact us.

Please direct any questions about the IRB's actions on this project to:

Janell Barker, Senior IRB Coordinator - (970) 491-1655 Janell.Barker@Colostate.edu
Evelyn Swiss, IRB Coordinator - (970) 491-1381 Evelyn.Swiss@Colostate.edu

Barker, Janell

[redacted]

Barker, Janell

Includes:

Approval is for a maximum of 130 participants from two classrooms using the approved consent form to obtain consent. Any changes to the consent or protocol must be submitted for review and approval prior to implementation.

Approval Period: July 11, 2011 through June 23, 2012

APPENDIX C. DEMOGRAPHIC QUESTIONNAIRE

Demographic Questionnaire
Instruction:
Answer the following questions by writing or circling the letter or number to response that best describes about yourself.

1. Please indicate your name. ________________________ ________________________
(Last Name) (First Name)

2. Please indicate your gender. a. Male b. Female

3. Please indicate your age. __________________

4. Please select major of your study.

   a. Mechanical Engineering
   b. Engineering Science
   c. Other (please indicate): ________________________________

5. Please select the category that includes your current cumulative GPA

   a. < 2.00 b. 2.01 – 2.50 c. 2.51 – 3.00 d. 3.01 – 3.50 e. 3.51 – 4.00

6. How would you rate yourself on the following?

	None		**Average**		**Outstanding**
a. Engineering analysis skills. What is your paper-and-pencil, mathematically based problem solving ability?	1	2	3	4	5
b. Engineering fabrication skills. How are you at building things?	1	2	3	4	5
c. Engineering intuition. What is your ability to grasp engineering problems before applying formal analysis to them, if at all.	1	2	3	4	5

7. Prior to Engineering Design Practicum, did you ever participate in any of the following activities?

	Never		**Sometime**		**All the time**
a. Drawing or sketching?	1	2	3	4	5
b. Designing or building models, or creating arts & crafts?	1	2	3	4	5
c. Taking apart and/or building cars, computers, appliances, etc.?	1	2	3	4	5
d. Large scale fabrication, i. e. machining or construction.	1	2	3	4	5

APPENDIX D. STUDENT PERMISSION TO RELEASE ACADEMIC RECORDS

Student Permission to Release Academic Records

Under the terms of the Family Educational Rights and Privacy Act (FERPA),a student's educational record is, with certain exceptions, held confidential by Colorado State University. A student may grant permission for information to be provided to a third party by completing this consent form.

This release pertains ONLY to academically related education records, and may not be used for the purpose of releasing records related to employment, medical records, financial aid, disciplinary actions, or law enforcement. Any such requests must be directed to Student Employment Services, Hartshorn Health Service, Student Financial Services, or Conflict Resolution and Student Conduct Services, as appropriate.

Requested by (student):	Release to (recipient):
________________________________	Ibrahim Badaruddin
Last Name (print) First Name	Last Name (print) First Name
________________________________	Researcher
CSU ID	Relationship to student
	1588, School of Education, Colorado State University
	Address
	Fort Collins, CO, 80523
	City, State, Zip code

Purpose of Authorized Disclosure:____

I grant permission to employees of Colorado State University to release to the recipient above (select one):

☐ Any available academic records related to academic advising (e.g., grades, academic standing, etc.) that the University maintains

☐ Please indicate for what academic year (August to August) this applies:________________________

OR

☒ The following specific academic information (this request is valid on a one-time basis only):____________

Mechanical Engineering Design Practicum (MECH 486A and B) required course grades only.
Final course grade MECH 486B. No other grades or information will be collected.

By signing this form, I agree that:

- I voluntarily authorize the release of my academic records to the individual above
- I may revoke or amend my authorization at anytime
- Any previous confidentiality requests on file with the university remain ineffect

____ ______________________________

Student Signature Date

Registrar/FERPA/Student Release.doc

Rev.January23,2008kk

APPENDIX E. PERMISSION TO USE AND REVISE TEAM CLIMATE INVENTORY (TCI)

ACNSMail :: RE: Team Climate Inventory (TCI) - Permission to use for dissertation research

Subject **RE: Team Climate Inventory (TCI) - Permission to use for dissertation research**
Sender West, Michael <m.a.west@lancaster.ac.uk>
Recipient badar <badar@lamar.colostate.edu>
Date 13.06.2011 02:28

I am happy to agree to your using the instrument for research. I hope the research is successful in advancing understanding.

Best wishes

Michael West
Professor of Organizational Psychology
Lancaster University Management School
Lancaster University
LANCASTER
LA1 4YX
Tel: 01524 593019
Fax: 01524 594720
Mobile: 0777 833 2424
email: m.a.west@lancaster.ac.uk
website: www.lums.lancs.ac.uk

-----Original Message-----
From: badar [mailto:badar@lamar.colostate.edu]
Sent: 12 June 2011 21:35
To: West, Michael
Subject: Team Climate Inventory (TCI) - Permission to use for dissertation research

Dear Dr. West,

I am completing my doctoral dissertation entitled "The impact of creativity, engineering knowledge, and design team interaction on engineering design projects" at Colorado State University, USA. I would like to ask permission to adapt and/or duplicate your instrument entitled "Team Climate Inventory" for my research use. Material to adapt and/or duplicate for the purpose of my study will involved 42 items (attached). Dr Anderson and your name will be cited for your work on TCI. Your electronic signature and/or e-mail reply is granted to signifies a permission of using TCI for my dissertation research. Thank you for your attention and I am looking forward for your reply.

Best regards,

Badaruddin Ibrahim
PhD Candidate,
Colorado State University,
United States of America

https://acnsmail.colostate.edu/?_task=mail&_action=print&_uid=3578&_mbox=INBOX[6/13/2011 10:56:16 AM]

APPENDIX F. SCHOLASTIC TESTING SERVICE, INC.

Scholastic Testing Service, Inc.
480 Meyer Road
Bensenville, Illinois 60106-167

STS Torrance Tests
Scoring Center
4320 Green Ash Drive
Earth City, MO 63405

APPENDIX G. PERMISSION TO USE AND REVISE THE STUDENT PRODUCT ASSESSMENT FORM (SPAF)

ACNSMail :: Re: Permission to adapt SPAF

Subject Re: Permission to adapt SPAF
Sender Renzulli, Joseph <joseph.renzulli@uconn.edu>
Recipient badar <badar@lamar.colostate.edu>
Date 06.03.2012 15:13

Dear Badar,

You have my permission but I would like to receive a copy of the adapted version.

Joe

Joseph S. Renzulli
--
Joseph S. Renzulli, Director
The National Research Center on the Gifted and Talented
University of Connecticut Board of Trustees Distinguished Professor
Raymond and Lynn Neag Professor of Gifted Education and Talent Development
Winner of the 2009 Harold W. McGraw, Jr. Prize in Education

Visit our award winning website www.gifted.uconn.edu/ for information about our summer and academic year programs including Confratute, Three Summers Master's Degree Program, On-Line Courses, UConn Mentor Connection, Parenting Specialist Help, and the latest research from The National Research Center on the Gifted and Talented.

On 3/6/12 12:27 PM, "badar" <badar@lamar.colostate.edu> wrote:

> Hello Dr Renzulli,
> My name is Badar and I am a PhD candidate at School of Education, Colorado State University, Fort Collins, CO. I have email you last year asking permission to use your instrument (SPAF) in my dissertation research in which examining the relationship between creativity, engineering knowledge, and teamwork on design solutions/products. In your reply, you gave me your permission to use the SPAF as long as I provide the appropriate citation and send you a copy of the results when I completed my study. For the last 2 month, I have been working with my advisor and my dissertation committee on your current SPAF and we decided to make appropriate adaptation to fit with the expected outcomes from the specific group in my study which is senior mechanical engineering students here at CSU. Therefore, the purpose of this email is to ask permission for me and my dissertation committee to adapt the format and the items from the SPAF. I will cite and credit your work with Dr Reis in my dissertation and will provide you with the final results of the adapted instrument. Thank you for your attention and I apologize if I'm not using the right language in this email. I am looking forward for your reply and have a nice day.
>
> Best regards,
> Badaruddin Ibrahim
> PhD Candidate
> School of Education
> Colorado State University
> Fort Collins, CO
> Email: badaruddin.ibrahim@colostate.edu
> Office phone: (970) 491 6599

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APPENDIX H. SENIOR DESIGN OUTCOME JUDGING SHEET

Engineering Days 2012

JUDGING CRITERIA

Instruction: Please fill out the team information below. Do a quick overview of the entire body of work. Then do a careful and detail examination of the design product/solution. Listen carefully to the design team's informal description of the design challenge and their design solution and approach. It is completely appropriate during this evaluation to query the team and ask appropriate question(s) related to the points being evaluated in this rubric.

Circle the number that best represents your assessment of the stated item. Write your comments (if any) on page 2.

Project Title : ____

TECHNICAL APPROACH AND FINAL DESIGN SOLUTION.

	Item	**To a limited extent**		**Somewhat**		**To a great extent**
1	Is the design objective(s) clearly identified and readily apparent in the early stages of the team's product development?	1	2	3	4	5
2	Did the team define the topic or problem in such a manner that a clear understanding about the nature of the product emerges shortly after a review of the design solution?	1	2	3	4	5
3	Did the team focus or clearly define the design problem so it represents a relatively specific problem within a larger area of study?	1	2	3	4	5
4	Did the team identify and/or list any constraints for the project/product?	1	2	3	4	5
5	Is there evidence of novel approaches to address the design constraints?	1	2	3	4	5
6	Is there evidence that the team used resource materials or equipment that are more advanced, technical, or complex than materials ordinarily used?	1	2	3	4	5
7	Did the team use several different types of resource materials in the development of the product?	1	2	3	4	5
8	Did the team select technically appropriate creative application of theory(s), equation(s), and/or engineering tool(s) toward the design solution?	1	2	3	4	5

Joseph S. Renzuli & Sally M. Reis (1997, 2004)

	Item	To a limited extent		Somewhat		To a great extent
9	Does the design solution reflect a logical sequence of steps or events that ordinarily would be followed when carrying out a design challenge in this area of study?	1	2	3	4	5
10	Are the design methods varied and/or revised?	1	2	3	4	5
11	Was the solution optimized by iteration and refinement through analysis using best methods?	1	2	3	4	5
12	Is it clear that the major goal of the project was for purposes other than merely reporting on or reproducing an existing idea?	1	2	3	4	5

OVERALL ASSESSMENT. Considering the design solution/product as a whole, provide a rating for each of the following factors

	Item	Poor	Below average	Average	Above average	Outstanding
13	Originality of the idea.	1	2	3	4	5
14	Achieved objectives stated in plan.	1	2	3	4	5
15	Reflects advanced familiarity with the subject matter.	1	2	3	4	5
16	Reflects a level of quality beyond what is normally expected.	1	2	3	4	5
17	Reflects care, attention to detail, and overall pride in the project/product.	1	2	3	4	5
18	Reflects a commitment of time, effort, and energy.	1	2	3	4	5
19	Reflects an original contribution.	1	2	3	4	5

Additional comments:

Joseph S. Renzuli & Sally M. Reis (1997, 2004)