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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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.
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
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).
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.
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