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AN EXPERIMENTAL INVESTIGATION OF THE STATE OF CREATIVITY, CRITICAL
THINKING AND CREATIVITY TRAINING IN UNDERGRADUATE ENGINEERING
STUDENTS

by

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A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Industrial Engineering and Management Systems
in the College of Engineering and Computer Science
at the University of Central Florida
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ABSTRACT

This research explores creativity and critical thinking skills in undergraduate engineering students. The study undertook two experiments in order to gather a better understanding of several factors regarding the interactions between students' creative abilities and the effects of the undergraduate engineering curriculum. Experiment 1 focused on the differences in creative and critical thinking skills in freshman versus senior undergraduate engineering students. Experiment 2 centered on the variation in the effects of long-term versus short-term creativity training on senior engineering students. Creative skill was measured using the Test for Creative Thinking – Drawing Production (TCT-DP) developed by Urban and Jellen (2010). Measurements for critical thinking utilized the Watson-Glaser Critical Thinking Assessment (WGCTA) (Watson & Glaser, 2008).

Experiment 1 found evidence suggesting the freshman engineers within the study were more creative than senior engineers ($F = 3.159$, $P\text{-Value} = 0.078$). Surprisingly, there was no evidence suggesting the senior engineers had superior critical thinking skills over the freshman engineers ($F = 1.054$, $P\text{-Value} = 0.306$). The study groups' data was also compared to the normative data provided by the WGCTA test, in order to determine the standing of the two engineering sample groups against the general population. The study's freshman group average ranked in the 70th percentile (freshman engineers' average) when compared to the normative general population's average (50th percentile). The senior participants, on the other hand, scored significantly lower than their corresponding normative group, moving from the 50th percentile (normative average) to slightly above the 35th percentile (senior engineers' average). Based on

this evidence, current engineering education methods are detrimental not only to the creative skills of engineering students, but their critical thinking capabilities as well.

Experiment 2 results suggested that long-term creativity training provides statistically significant improvements over short-term creativity training ($F = 40.381$, $P\text{-Value} = 0.000$). This significance was established even though the long-term group was found to have been trained inadvertently before the start of their official training, simply by their knowledge of the course's requirements to provide creative solutions. As such, these results suggest both that continuous creativity training benefits the recipient individuals, and that beginning a more creative approach to collegiate engineering curricula may start as easily as initiating courses with the known expectation that students use creativity in their problem solving whenever feasible.

This study provides new insights into the state of creativity and critical thinking in undergraduate engineers. Based on the resulting data, engineering education must be examined and restructured to provide students with the necessary tools to improve their creative and critical thinking skills. Through the use of creativity and critical thinking training and instruction methods, educators can effectively address these observed deficiencies, resulting in engineering students being better prepared for their professional lives within the 21st century workplace.

This dissertation is dedicated to my mother, *Ilia Sola*, for her sacrifice, support and unwavering belief in me.

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LIST OF ABBREVIATIONS

Bfd	TCT-DP Sub Score – Boundary breaking that is fragment dependent
Bfi	TCT-DP Sub Score – Boundary breaking that is fragment independent
CA	Pre-Training Creativity Course (Long-Term Creativity Training) Senior Participants
CB	Post-Training Creativity Course (Long-Term Creativity Training) Senior Participants
CCTT	Cornell Critical Thinking Test
Cl	TCT-DP Sub Score – Connections made with Lines
Cm	TCT-DP Sub Score – Completions
Cn	TCT-DP Sub Score – Continuations
Cth	TCT-DP Sub Score – Connections made to produce a Theme
FA	Incoming Freshman Group (No Creativity Training)
Hu	TCT-DP Sub Score – Humor/Sensitivity
ICC	Intraclass Correlation Coefficient
Ne	TCT-DP Sub Score – New Elements
Pe	TCT-DP Sub Score – Perspective
STEM	Science, Technology, Engineering and Mathematics
STEAM	Science, Technology, Engineering, Art and Mathematics
TCT-DP	Test of Creative Thinking – Drawing Production
TTCT	Torrance Tests of Creative Thinking
Uca	TCT-DP Sub Score – Unconventionality A

Ucb	TCT-DP Sub Score – Unconventionality B
Ucc	TCT-DP Sub Score – Unconventionality C
Ucd	TCT-DP Sub Score – Unconventionality D
WA	Pre-Training Creativity Workshop (Short-Term Creativity Training) Senior Participants
WB	Post-Training Creativity Workshop (Short-Term Creativity Training) Senior Participants
WGCTA	Watson-Glaser Critical Thinking Appraisal

CHAPTER ONE: INTRODUCTION

Engineers are in the business of creativity and innovation. In the last two hundred years, "more than half of the major life-altering, technological and social innovations introduced to the world came into being", and engineers were responsible for a large portion of those technological breakthroughs (Puccio & Cabra, 2010). Now more than ever, the world is in a state of continuous innovation, in need of engineers with creative and critical thinking skills capable of solving present and future challenges (Tucker, 2001; Twohill, 2012).

The Partnership for 21st Century Skills, a consortium focused on infusing 21st Century Skills into education, conducted a study to determine the skills employers found essential to performing in today's workplace (Casner-Lotto & Barrington, 2006). Based on the employers' responses, the study gathered a list of twenty skills and categorized them as basic skills or applied skills. Figure 1 details the list and categorization developed through the report.

Basic Knowledge/Skills	Applied Skills
English Language (spoken)	Critical Thinking/Problem Solving
Reading Comprehension (in English)	Oral Communications
Writing in English (grammar, spelling, etc.)	Written Communications
Mathematics	Teamwork/Collaboration
Science	Diversity
Government/Economics	Information Technology Application
Humanities/Arts	Leadership
Foreign Languages	Creativity/Innovation
History/Geography	Lifelong Learning/Self Direction
	Professionalism/Work Ethic
	Ethics/Social Responsibility

Figure 1: List of Essential Skills Necessary for Success in the 21st Century Workforce (Casner-Lotto & Barrington, 2006)

The study found that creativity/innovation and critical thinking skills were some of the most desired skills for workplace entrants with four-year college diplomas. Specifically, both of these skill sets ranked within the top ten. Figure 2 details the order of importance of the skills as reported by 382 to 409 respondents (employers) involved in the study. It is apparent that creativity and critical thinking are essential to workplace performance. This suggests that critical thinking and creativity must be given the same level of emphasis in engineering education as math and sciences to ensure engineers are ready for the 21st century workplace.

Rank	Skill	Percentage
1	Oral Communications*	95.4%
2	Teamwork/Collaboration*	94.4
3	Professionalism/Work Ethic*	93.8
4	Written Communications*	93.1
5	Critical Thinking/ Problem Solving*	92.1
6	Writing in English	89.7
7	English Language	88.0
8	Reading Comprehension	87.0
9	Ethics/Social Responsibility*	85.6
10	Leadership*	81.8
11	Information Technology Application*	81.0
12	Creativity/Innovation*	81.0
13	Lifelong Learning/ Self Direction*	78.3
14	Diversity*	71.8
15	Mathematics	64.2
16	Science	33.4
17	Foreign Languages	21.0
18	Government/Economics	19.8
19	History/Geography	14.1
20	Humanities/Arts	13.2

Figure 2: Ranked Skills Based on Employer Opinion (Reproduction of Table 5 from *Are They Ready to Work?* Report) (Casner-Lotto & Barrington, 2006)

Innovation as a process requires both creativity and critical thinking in order to be successful. Theoretical frameworks on the innovation process generally distill down into stages: idea generation, development of the concept, evaluation and selection of the concept, product development, and finally implementation (Dreiling & Recker, 2013; Berry, Shankar, Parish, Cadwallader, & Dotzel, 2006; Nagji & Tuff, 2012). Critical thinking skills are valued in this framework, since multiple stages require the definition and understanding of problems, as well as definition of the original problem the company needs to solve through innovation. Creativity plays a role in the ideation steps within the innovation process through the many stages of the product or service's lifecycle as other issues hamper its implementation. The innovation process for business is driven by these two critical skills. As such, it is essential to understand the state of both within college engineering students, and find methods to address any deficiencies found.

Significance of Research

As the employer survey data suggests, creativity and critical thinking are essential tools for the 21st century workplace. Engineers are in the business of innovation, and creativity is the bedrock of that business. Critical thinking also plays a vital role in innovation. With these skills as a foundation, engineers can create the solutions needed to address the challenges of the world.

To better equip engineers for the problems they must address in the future, creativity and critical thinking must be developed as a key component of their engineering education. By understanding the state of creativity and critical thinking in freshman and senior engineering students, statistical conclusions can be drawn and deficiencies addressed through appropriate training and instruction. This research then moves a step further, by studying the effects of short-

term versus long-term creativity training. The measurable improvements of each were compared in order to determine what will provide the most significant impact for students.

This study provided a deeper understanding of the current states of creativity and critical thinking in engineering undergraduates. It also explored evidence regarding the duration of the creativity training needed in order to effectively address any declines that may have occurred. Both of these contributions to creativity literature can provide a basis for future creativity and critical thinking training of undergraduate engineers.

Theoretical Foundation of Work

Employability surveys, such as the aforementioned, identify the need to produce more innovative engineers who are capable of creative problem solving. Instead, signs of negative trends in creativity appear in many studies (Kim, 2011; Genco, Holtta-Otto, & Conner Seepersad, 2012). The findings of these studies suggest current pre-college and college education, including engineering education, have been driving creative thinking down over many years to its present state. Based on the seriousness and urgency of this problem, special attention must be paid in determining its severity and how best to reverse the negative effects which have already occurred. This dissertation explored the effects twofold: studying the differential effects of creativity and critical thinking to determine how undergraduate engineering coursework affects engineers, and exploring the effects of short-term versus long-term creativity training on upper division undergraduate engineering students. These two experiments develop a better understanding of the problems, and potential remedies, for the development of creative and critical thinking abilities in undergraduate engineers.

The questions addressed within this research stem from several studies. Genco et al. (2011) looked at the creative abilities of freshman and senior engineering students with and without creative training, in the form of empathic design. The researchers noted that senior-level students did indeed display abilities indicative of their engineering education, but lacked in the more free-form creativity the freshmen displayed. The study concluded that, overall, freshman engineering students had a statistically significant advantage in terms of creative output. Other studies also point to the same conclusion of diminished creative abilities after engineering coursework (Genco, Holttä-Otto, & Conner Seepersad, 2012).

Genco et al. conducted a study on the innovation potential of undergraduate engineers (2012). This evaluated students' creative skills by asking for a new design for an alarm clock, a standardized real-world design problem. Through the use of such a ubiquitous object, this experiment lends itself to the negative effects of design fixation and expert bias (Jansson & Smith, 1991; Woltz, Gardner, & Bell, 2000). Design fixation is the implementation of previously learned information or patterns in order to solve a problem, regardless of their applicability or usefulness. Though both groups (freshmen and seniors) had experience with alarm clocks in everyday life, seniors may have been at a greater disadvantage, as they would have had a more developed knowledge of the internal workings and functions of the alarm clock gained through their coursework. This drove them to less creative potential solutions by re-using common alarm clock design elements, regardless of their actual design necessity. By contrast to these types of design challenges, the Test for Creative Thinking – Drawing Production (TCT-DP) used for this study is suitable for both freshman and senior groups, and places emphasis on overall creative production.

Since critical thinking is important as a means to analytically solve problems and also as a driver for creativity, it is vitally important to understand the effects of the engineering curriculum on the critical thinking skills of undergraduates as well. Prior studies on critical thinking provide a less clear picture of the effects of engineering education on critical thinking skills. Douglas (2012) conducted a study which found evidence that undergraduate engineering students performed better on a standard critical thinking assessment than graduate engineering students. The researcher noted that the difference was likely due to graduate students answering fewer questions during testing. As such, they suggested that it was possible there were no differences between the groups. A study by Ozyurt and Ozyurt agreed with this result (2015). Though this would suggest a potential reduction in critical thinking skills, other studies and assessments (normative data) point to an improvement in overall critical thinking abilities.

Research largely suggests that critical thinking improves as a result of college experiences, including both coursework and college life. Mines et al. (1990) studied how senior college students' critical thinking abilities were affected by their college experience when compared to freshman college students. A group composed of freshman, senior and graduate participants was evaluated using the Reflective Judgement interview, Watson-Glaser Critical Thinking Appraisal (WGCTA) and Cornell Critical Thinking Test (CCTT). The most relevant finding of this research was that seniors scored significantly higher than freshman students. When compared to the normative data for the WGCTA, the freshmen in the study scored lower than their equivalent norms, while the seniors in the study scored at the normative average. Many studies also suggest this trend as well (Watson & Glaser, 2008; Pascarella, 1987; Keeley S. M., 1992; Spaulding & Kleiner, 1992). Some studies even suggest that campus culture and out-of-

class experiences may play a role in the improvement of critical thinking (Tsui, 2000; Terenzini, Springer, Pascarella, & Nora, 1995).

Research Questions

Studies on creativity and critical thinking largely focus on the general population. Studies specifically limited to engineering students show decreases in creativity. Those focused on critical thinking suggest no change between college grade levels. Though these studies provide a cornerstone for their respective topics, more work is needed to determine the current state of creativity and critical thinking skills in engineering students. With a better understanding of the current state of these abilities in engineering undergraduates, any deficiencies found can be proactively addressed.

The decline in creativity seen throughout the literature can be addressed through creativity training. However, the impact of different methods and durations of these trainings must be understood in order to improve creativity in engineering undergraduates by the most efficient means. As there was found to be a gap in the research comparing creativity training duration to creative skill impact, this study sought to provide those answers in the field of research.

This study also fills the research gap regarding critical thinking development in engineers through not only internal major comparisons between engineering student groups, but also comparisons to the general population as well. To address the needs discussed, this dissertation explored the following research questions:

- Are freshman engineering students more creative than senior engineering students?

- Are senior engineering students better critical thinkers than freshman engineering students?
- Is long-term creativity training more effective than short-term creativity training?

Contribution to the Body of Knowledge

Creativity and critical thinking literature extensively address the states of creativity and critical thinking in the general population. There is a definite need to understand the current state of creativity and critical thinking in engineering students specifically. Additionally, the impacts of creativity training must be understood in order to determine if longer-term creativity training is measurably more beneficial than shorter-term workshops or “boot camps”. This research took previously conducted studies further by compiling data on the current states of creativity and critical thinking abilities in freshman and senior engineering undergraduates. Additionally, the differences in improvements of short-term versus long-term creativity training were compared, in order to determine the most effective approach of incorporating creativity training into the engineering curriculum.

The first experiment studied the creative abilities of freshman and senior engineering students using the Test of Creative Thinking - Drawing Production (Jellen & Urban, 1986). The study focused on a sample of undergraduate engineers with no creativity training. As there is extensive evidence of the benefits of creativity training (Clapham M. M., 1997; Cropley & Cropley, 2000; Gist, 1989), the study explored the differences in the creative abilities of freshman undergraduate students as compared to senior undergraduate students. This experiment also tested the critical thinking abilities of both the freshman and senior engineering students through the Watson-Glaser Critical Thinking Appraisal (Watson & Glaser, 2008). The gathered

data compared both analytical and creative thinking abilities, as well as any statistical interactions between the results. This was intended to give a better understanding of what engineering students are learning and losing through their engineering coursework.

In addition to the preceding experiment, this study explored the effects of short-term and long-term creativity training on undergraduate seniors. There is strong evidence to support the improvement of creative skills through the use of creativity training, but it is typically focused on limited engagement creativity training (Clapham M. M., 1997; Genco, Holtta-Otto, & Conner Seepersad, 2012; Genco, Johnson, Holtta-Otto, & Conner Seepersad, 2011). Longer-term training and course-length training have been studied extensively, but without insight to the relative improvements over the shorter-term training (Cropley & Cropley, 2000; Mahboub, Portillo, Liu, & Chandraratna, 2004). Considering the considerable time and effort needed for creativity courses versus a single creativity workshop, it is essential to understand the additional benefits of providing a longer-term training, if any exist.

Through the second experiment, participants were tested before and after creativity training sessions. The study was divided into two separate groups: one in an existing leadership and creativity course, and the other in an engineering capstone course's singular creativity training workshop. The long-term creativity training lasted six weeks while the short-term training was concluded in an hour and a half. The data collected through the TCT-DP could then be used to understand the benefits of longer training, if any were present.

The creativity course and workshop shared the same basic content. Both of the training sessions (course and workshop) were taught by the University of Central Florida College of Engineering Industrial Engineering and Management Systems faculty. Though the full content of

the course could not be covered in the workshop session, the essential concepts could be transferred and presented in a shorter format.

These two experiments significantly expand our understanding of the current state of creativity in engineering undergraduates, while also determining the most impactful way to address deficiencies in creativity. Though there is discussion of these topics in the literature in isolation, this study addressed comparisons between engineering students at varying grade levels.

Though there are signs that the engineering curriculum currently taught at schools of higher education may be negatively affecting the creativity of student engineers, an abundance of research attempts to define the processes and pitfalls present in order to stimulate creativity throughout academia (Belski, 2009; Badran, 2007; Court, 1998; Blicblau & Steiner, 1998). With an understanding of available studies in creativity, there are positive signs that the damage done to individual and team-based creativity is repairable. The experiments developed herein provide a better understanding of the effects of engineering education on creative ability, as well as the ability of creativity training to correct stagnation or decline.

CHAPTER TWO: LITERATURE REVIEW

What is Creativity?

Engineers are in the business of innovation, and creativity is the foundation of that business. With this foundation, engineers create the solutions needed to address the challenges of the world. To better understand the implications of creativity and innovation, we must first understand what these concepts truly encompass.

Creativity was once considered a divine gift, sometimes completely disassociated from the person who developed the creative works. The Greeks thought creativity to be the result of a person's daimon, or guardian spirit (Runco & Albert, 2010). For much of history, creativity was considered the ability of a few, until research began to suggest it might be possible for creativity to be a tool for all. Researchers found that creativity was not the sole ability of a privileged few, but the potential ability of anyone with a capacity to learn (Andreasen, 2006; Gelb, 2000; Starko, 2014).

Creativity is defined as the development of ideas that are novel and appropriate (Starko, 2014). An extension of this definition also addresses the need for utility in the product which that idea produces (Andreasen, 2006). An idea that is novel but is of little use to anyone would, in fact, not be truly creative based on these definitions. Considering the work of an engineer, this definition can be considered valid since most creative engineering work is secured through patents. The U.S. Patent and Trademark Office put forth these very same requirements on originality, utility and feasibility (United States Patent & Trademark Office, 2013). This definition is expansive enough to grasp an engineer's physical products, but can also encompass a composer's musical score or an artist's painting. The artist's and composer's products conform

to the requirements of originality and appropriateness/usefulness if they evoke emotion or function in a novel way. The originality can come from truly unique ideas, or the combination of or improvements to current ideas. Kohn et al. "argue[d] that people's ability to combine categories is related to their ability to produce original, high-quality products", which would make their resulting products creative (2011). Combinations and incremental improvements like these are closely associated with innovation. Creativity and innovation are sometimes colloquially synonymous, though there is some delineation to consider.

Creativity comes in several forms. "Little c" creativity is the type exercised by everyone, every day. Creativity in this range is what allows us to create unique language patterns, interpret music and write papers within our daily lives. "Big C" creativity is the creative genius from the likes of Amadeus Mozart, Isaac Newton, Pablo Picasso and Albert Einstein. This level of creativity usually brings step changes in human understanding, regardless of domain (Andreasen, 2006; Starko, 2014). Innovation lies within the range of "little c" and "big C". Within the context of this review, innovation is an iterative change to an existing idea.

Creativity is largely dependent on the person of whom it is being asked. There is a myriad of theories on creativity and cognitive human production. Developmental theories such as Maslow's Hierarchy of Needs capture creativity in terms of human needs and experience. The theory postulates that when basic needs are met, such as physiological security and safety, the inter- and intra- relationships of the individual provide the nuances that lead to a self-actualized person (Starko, 2014). Self-actualization is a state wherein individuals are willing to take risks, be playful without paying mind to judgments and are open to abstract ideas. At this level, an individual's capacity has been freed from lesser needs and allows for higher-order thinking. This is where creativity happens (Starko, 2014). Though Maslow's theory is one method of

understanding the psychological means of understanding creativity, many other theories exist, including cognitive creativity.

Cognitive theories consider the creative potential of a person to be a matter of the correct cognitive processes taking place within the individual's brain. Since human brains are capable of plasticity, these cognitive processes can be taught and learned. The most common cognitive processes studied in the field of creativity are divergent thinking and convergent thinking. Divergent thinking exercises make up a large portion of the creativity assessments available for creativity research today (Guilford, 1950; Cropley A. J., 2000; Clapham M. M., 1997). These two samples of creative theories provide an idea of how creativity takes place within human cognition. The theories also point to creativity not as the privilege of a few individuals, but instead as a skill that can be taught.

As important as the definition of creativity may be, how creativity is learned, exercised and expressed is essential for creative development. There are a variety of skills used by creative people to influence their thought processes in order to enhance their creativity (Gelb, 2000; Root-Bernstein & Root-Bernstein, 2001). Of these, the most often studied are Abstraction, Analogies, Divergent Thinking, Empathizing, Modeling (Prototyping) and Synthesis. They are typically analyzed in terms of established tests to determine changes in these styles of thinking.

An analogy is a simple way to communicate novel ideas, as it provides a common starting point for others to understand the potential of a new concept. This can lead to incremental changes that in turn become innovations, or breakthrough ideas (Chan & Schunn, 2014). Empathizing is also a studied approach that, like the use of analogies, provides a means for others to understand the innovation. The basis of this process is the human need to empathize with the feelings of others. By understanding how others may struggle with products or services,

a creative individual can craft solutions that may totally redefine an industry (Genco, Johnson, Holtta-Otto, & Conner Seepersad, 2011).

Another essential creative skill is modeling, or prototyping. Modeling is a necessity for any idea worth bringing to the world. Whether a product is physical, functional, theoretical or imaginary, concepts grasped by the mind using other creative tools come into being through the use of modeling. With a model or prototype, previously unforeseen obstacles can be addressed and the idea tangibly shown to others. The mind is a powerful tool, but at some point we need to share our insights in a way others can understand. Prototyping is an essential creative skill, as it allows for an individual to find and solve problems through real world interactions (Gelb, 2000; Root-Bernstein & Root-Bernstein, 2001; Kelley, Littman, & Peters, 2001).

Though individual creativity is important in any context, most projects within universities and companies are multi-disciplinary in nature. Group creativity plays a vital role in the developments and innovations of companies globally. Work groups and hot groups are the backbone of the corporate world. The idea that a group of individuals can be more productive and creative than a singular individual is a cornerstone of the business mindset, but this may be oversimplified. Individual ideation proves to be equally creative, if not more so, than group ideation in most of the studies presented in the articles within *Group Creativity: Innovation through Collaboration* (Paulus & Nijstad, 2003), as well as other texts (Sawyer, 2010).

Even with this limitation, group ideation proves beneficial when certain guidelines are followed. For example, limiting a group to a specific idea can be detrimental to the creativity process. Constraining a group ideation session from the start with an overly limiting idea can stagnate the group's ability to be truly innovative in their suggested solutions to a problem. Groups will follow patterns, especially if given by an authority figure; as a result, they will feed

back the same idea that was provided with little alteration. Group diversity and dissent within the group have the opposite effect. These two catalysts act to infuse different viewpoints within the group. This is vital for creative teamwork, as groups have a tendency to think with a 'pack mentality', or to think collectively. Human cooperation and interaction tend to lead large groups to follow the group thought so as to fit in. This is detrimental in creative teamwork, as the hope is to create novel and useful solutions which are typically outside the comfort of the status quo (Paulus & Nijstad, 2003).

Teams typically work within the context of a brainstorming session. Some of the most innovative companies in the world use this technique as an essential part of their team creative processes; however, care must be taken to maintain the group's creativity and keep it alive. As with other pitfalls in group creativity, brainstorming sessions must maintain tight runs of engagement. The focus of a brainstorming session is on creating a relaxed but energetic space to share any and all ideas. Any pre-judgments or overly constraining seed ideas can stagnate the brainstorming session, and stop the flow of creative ideas. The brainstorm benefits from the fact that individuals are more creative than groups (in terms of the number of ideas generated in a given time), while also exploiting the multidisciplinary aspect of the team. With careful facilitation, brainstorming can be an essential creative tool for teams (Kelley, Littman, & Peters, 2001; Paulus & Nijstad, 2003; Sawyer, 2010).

Understanding the current state of creativity for both individuals and groups is a necessity for creativity training research. Better comprehension of the underlying processes can support the development of more effective creativity training programs. The concern of declining creativity makes these training programs all the more necessary to reverse the negative effects seen in a variety of studies.

Creativity in Decline

Though the field of creativity contains much ongoing research, many of those studies show worrying trends. With some exceptions (Weinstein, Clark, DiBartolomeo, & Davis, 2014), studies indicate downward trends for creativity, in both the general population as well as in engineering students (Kim, 2011; Genco, Holtta-Otto, & Conner Seepersad, 2012). With such negative trends evident, the causes must be determined and corrected to counteract the existing degradation.

Creativity has been on a decline for quite some time. Studies show a sharp decrease in creative scores both from standardized creativity tests, as well as in evaluations of creative works over the past few decades (Kim, 2011). Kim's 2011 study used archival data on the Torrance Tests of Creative Thinking (TTCT) on a total of 272,599 kindergarten through twelfth grade students and adults in order to determine trends in their ability to think divergently. The study showed a downturn in creative thinking skills (i.e. fluency, originality and elaboration within the TTCT) from 1966 through 1974, and from 1990 to the present (see Figure 3).

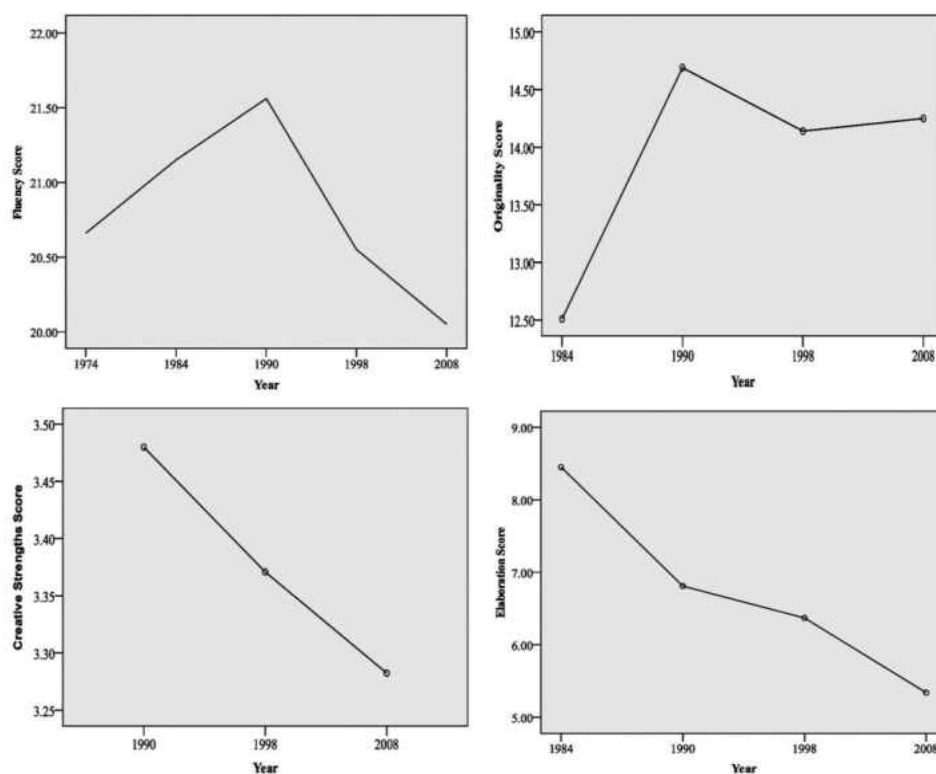


Figure 3: Partially reproduced results for Fluency, Originality, Creative Strengths and Elaboration for Given Years (Kim, 2011)

Though originality scores appeared to increase between 1984 and 1990 and flatten thereafter, Kim suggested that it could be an artificially inflated score. Kim explained that the test's originality scores are compared against an originality list which Torrance (1988) suggested be updated to be culturally specific and in sync with the times. In fact, the originality test used for the 1998 TTCT scoring was the same one originally developed in 1984: "Computers, iPods, cellphones, and other gadgetry may be common responses in 2011, but they were rare and fanciful in 1984 and are not included in the 1984 Originality Lists in use today" (Kim, 2011). This indicates that the originality scores may have been skewed more than is otherwise apparent from the study's data.

These results represent a significant loss of creative individuals capable of being trained in various technical careers that require innovation for true success. Though already troublesome, these results are not improved upon within the engineering curriculum in college-level courses.

Creativity in Engineering Students

The creative potential of engineers is negatively impacted by the very courses intended to teach them to be better engineers in their future professional lives. There is evidence indicating incoming freshman engineering students have the ability to develop more creative concepts than senior engineering students. In the aforementioned Genco et al. (2012) study to test the innovation potential of undergraduates, groups of freshman and senior engineering students were divided into innovation enhanced and non-enhanced subgroups. Researchers tasked each group with making improvements or redesigns to an alarm clock. The creativity-enhanced groups were given creativity training aides; specifically, manipulation restriction devices were given to these groups in order to simulate people with limitations, along with alarm clock innovation instructions (Genco, Johnson, Holtta-Otto, & Conner Seepersad, 2011). The non-enhanced group was only instructed to provide designs for a new alarm clock. The results show the freshmen's enhanced group significantly ahead in terms of design originality and quality, as demonstrated in Figure 4 (Genco, Holtta-Otto et al., 2012).

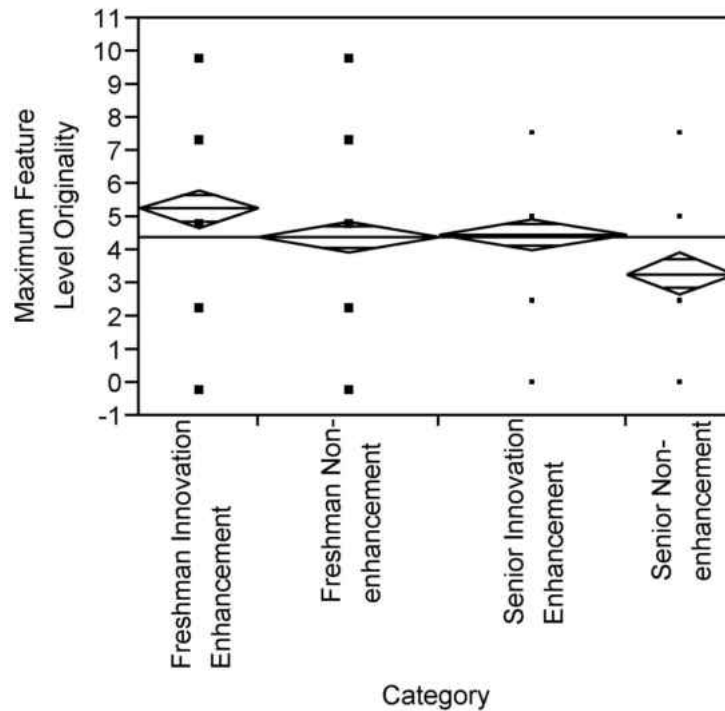


Figure 4: Reproduced Graph of Originality of Ideas between Freshmen and Seniors (Innovation Enhanced vs. Non-Innovation Enhanced) (Genco, Holtta-Otto et al. 2012)

The results demonstrating the large gap between senior and freshman engineering students' creative skills are also telling. The originality scores between the seniors' creativity-enhanced group and the freshmen's non-enhanced group are seemingly identical. The freshman engineering students were able to creatively outperform even those seniors with a creative training advantage. This could be in large part due to design fixation on the part of the senior students, gained throughout their nearly completed engineering curriculum experiences.

Design fixation is the implementation of previously learned information or patterns in order to solve a problem, regardless of their applicability. This process is unintentional, and limits the output of conceptual designs (Jansson & Smith, 1991). The process of design fixation has much to do with the general design of cognitive processes. To minimize the processing

power needed on a daily basis, the brain is optimized to apply previously conceived or known solutions to problems similar enough to the problem at hand, so that the recalled solution is used instead of generating a novel solution (Andreasen, 2006; Smith & Kosslyn, 2007). This is a real concern to creativity research, as creativity can only occur when new ideas are formed. Applying previously-learned knowledge sabotages the creative process, preventing divergent and convergent thinking from taking place.

Several studies demonstrate the effects of design fixation on the levels of creativity demonstrated through their study tasks. Design fixation transfers related and unrelated design features from supplied supplemental information, sometimes in an unconscious manner. Study components are shown to some of the subjects in order to provide a baseline of current or state-of-the-art solutions. The resulting participant creations show definite signs of design fixation. In the example of the study using alarm clocks as a creative design exercise, the students with the most concrete and thorough engineering knowledge deviated little from the given alarm clock design (Genco, Holtta-Otto, & Conner Seepersad, 2012). In another study which requested new designs for book retrieval in a library, participant groups were supplied with sketches (in various levels of detail) of a handheld book retrieval tool. Participants again used various aspects directly from the supplied design, often without any real purpose towards creating the solution for the problem (Cardoso & Badke-Schaub, 2011). The alarm clock and book retrieval studies are indicative of the design fixation process, where aspects of an existing design are incorporated regardless of applicability or usefulness. Though transfer of benign aspects through design fixation is little more than a waste, more detrimental inclusions can occur when negative design aspects are transferred from the supplied information.

Negative transfer of information causes an individual, typically one with much experience, to use their established knowledge in order to solve a previously un-encountered problem. In creating a solution, the experienced individual does not fully evaluate the underlying differences between their previous experience and the problem at hand. As a result, they blindly or unknowingly apply their previous solution to the problem without giving it further consideration. The application of learned information created a negative transfer of a solution to the problem, as the problem needed further consideration to be solved fully (Besnard & Cacitti, 2005; Woltz, Gardner, & Bell, 2000; Hecht & Proffitt, 1995).

In a study to determine the ability of an experienced individual to find the correct solution to a problem within their domain of expertise, researchers asked experienced individuals (bartenders and waitresses) and non-expert individuals (graduate students, bus drivers and housewives) to determine and inscribe the water level on a tilted glass. The results show that those with experience provided significantly less correct answers than the non-expert individuals. This is an example of using previous experience to determine a new solution, resulting in negative transfer. Due to their work, the experienced individuals' perceived ideas of the correct water level were far more skewed than the average person's view of the same phenomenon (Hecht & Proffitt, 1995).

Woltz et al. not only found this effect to be true within the context of expert versus non-expert error rates, but experts executed the negative transfer at the "same speed as correct responses to familiar sequence trials" within the study (2000). Similar results were found in a separate study that aimed to understand a fatal error at a steelworks factory by an operator (Besnard & Cacitti, 2005). An experienced worker was in charge of running eleven thread drawing machines in a steelworks factory. One of these machines had release controls opposite

to those of the other machines. Because of this, when he intended to engage the safety system, the operator erroneously actuated the release of the coiled thread and was killed by its violent release. The study found that this accident was likely the result of a negative transfer of routine procedures. Negative transfer is the result of the application of known information to situations where that solution may actually be a problem. Negative information transfer is not only detrimental to creative output, but also results in extremely dangerous errors in some cases.

Student surveys also lend credibility to the findings of creativity research on engineering students. Kazerounian and Foley (2007) conducted a survey asking students and professors about how specific Maxims in Creativity were addressed through their engineering coursework. These maxims included learning to fail, leading by example and the search for multiple answers. Engineering students largely felt that these creative maxims were not addressed within their coursework. These results concur with the research seen throughout the literature review. In many cases, engineering education is not supporting the creative processes the students require for their work outside of academic life.

A trend of declining creativity is detrimental not only to students, but to engineering overall. With engineering being an innovation-focused profession, a decrease in creativity can be detrimental not only for the students, but to the employers who later hire those students for their varied talents. These studies, as well as others, are important in demonstrating the need for changes to be implemented throughout K-12 education and at the college level in order to curb the creative slump of the last 25 years. By making measured changes to the way education is approached, innovation and creativity may be renewed.

Creativity Enhancement

Though the current trend in creativity is negative, focus on addressing the world's decreasing creative abilities has increased. J.P. Guilford is considered to be one of the first to undertake the need to study and develop creativity (1950). With his work on IQ, creativity and his test of divergent thinking, Guilford led some of the first research on the subject. Current studies focus not only on improving the creativity of people in general, but place much more emphasis on enhancing the creativity of engineers in particular.

Brain plasticity is the brain's ability to dynamically change itself to adapt to a situation. The constant rewiring, strengthening and streamlining of processes in the brain allow it to learn how to think more creatively (Andreasen, 2006; Smith & Kosslyn, 2007). This ability made it reasonable for researchers to consider whether or not creativity could be a teachable skill, but proof was necessary to determine if creativity instruction could provide significant increase to creative abilities.

Studies have found that creativity training can, in fact, impact creative production in subjects (Mahboub, Portillo, Liu, & Chandraratna, 2004; Genco, Holttä-Otto, & Conner Seepersad, 2012; Clapham M. M., 1997; Clapham & Schuster, 1992; Birdi, 2005). All of the studies established that there were measured increases in creative production in each of their training-enhanced groups who were treated with creativity training exercises. This bodes well for training as a way to reinforce creative potential in individuals, especially for students within rigid academic curricula that need time to adapt in order to meet the requirements of a changing business landscape.

Engineering curricula throughout the world are now specifically targeting creativity as an area of increased focus (Badran, 2007; Baillie & Walker, 1998; Blicblau & Steiner, 1998;

Vzyatishev, 1991; Belski, 2009; Lewis, 2005). In Australia, Cropley and Cropley (2000) studied how the creativity scores of a set participant group were improved through creativity training. The students were provided with training through three lectures, then further counseled based on deficiencies found through testing. The control group was not provided the additional creativity counseling. The researchers found that there was a significant increase in creative potential, as measured by the Test for Creative Thinking - Drawing Production also used in this study's experimental research. Further, the study found that machines constructed by the counseled students were more elegant and creative than those of the non-counseled students. This supports the ability of tests of creativity to predict real world creativity to a reasonable degree.

Creativity counseling is not the only approach. Methods of creativity training are varied in their instruction strategies, duration and level of participant submersion in creative tasks. Speedstorming (Joyce, Jennings, Hey, Grossman, & Kalil, 2010), design by analogy (Chan and Schunn 2014), design by abstraction (Ward, Patterson, & Sifonis, 2004) and design by combinations (Kohn, Paulus, & Korde, 2011) are all methods of creativity enhancement explored by various researchers. Design by analogy, abstraction and combinations are all substantially supported throughout literature not only as forms creative production, but also as methods for explaining creative ideas to others (Gelb, 2000; Root-Bernstein & Root-Bernstein, 2001). These studies provide a basis for creativity training development that addresses different forms of learning more effectively, as well as varied approaches to creative production. All these studies show improvements to creative output when the enhancement techniques were present.

Exploration is now underway on many approaches to enhancing creativity, which largely tap into the known skills of creative individuals. Divergent thinking is a significantly researched and nurtured skill in the study and development of creativity (Plucker, Qian, & Schmalensee,

2014; Clapham M. M., 1997). Divergent thinking is an individual's ability to generate many solutions to a bounded problem, even impractical solutions. A typical example used in creativity training is, "How many ways can a paperclip be used?" (Mahboub, Portillo, Liu, & Chandraratna, 2004). Additional examples of divergent thinking in creativity literature include chair designs, uses for various objects, and the previously referenced study on alarm clock designs. Divergent thinking allows for the individual to think of radical ideas and concepts not typically linked to the subject at hand. As such, divergent thinking exercises can lead to creative and innovative connections that may not have been found through traditional thinking processes (i.e. analysis).

Several approaches address ways to enhance and integrate divergent thinking into a daily skill used without effort. Techniques typically focus on repetition, as with other practiced skills (Court, 1998; Gelb, 2000; Root-Bernstein & Root-Bernstein, 2001; Plucker, Qian, & Schmalensee, 2014). Fluency, or the ability to find multiple ideas for any given category, is heavily tied to divergent thinking and creative potential in general.

Studies suggest that divergent thinking training can be an effective tool to increase the overall divergent thinking potential of individuals (Clapham M. M., 1997). Clapham administered a study containing three groups, to test her hypothesis on the level of training necessary to benefit from divergent thinking enhancement. One study group received a thirty minute creativity session, with interactive exercises and a playful, relaxed environment. The ideation group received a very factual and short instruction on divergent thinking techniques and applications. Lastly, the control group received informational sessions with no creativity training. Clapham found that a full creativity training seminar had an almost identical result on divergent test composite performance to the much shorter divergent thinking improvement training. Divergent thinking skills, though not a complete picture of creative ability, have previously

proved to be a teachable skill. As such, divergent thinking should be a part of any creativity training program, as it can support the other creative processes in order to increase creative potential.

Expertise is another important aspect of creative potential. Though expertise can have undesired effects such as negative transfer, it is necessary in the overall creative abilities of an individual. In fact, Ericsson argues that creativity for some individuals may be confined only to their area of expertise. Considering the broad knowledge an expert has about their domain, they have the understanding of what has been done and what still remains to be done in order to move the profession forward. This distinct advantage allows for the expert to make combinations and connections that others would not be able to grasp (Ericsson, 1999).

To a certain degree, senior engineering students should be progressing towards a firm grasp of the knowledge necessary to flourish within their domain. College students also often have the advantage of working within a diverse campus where interactions can lead to an unforeseen connection of ideas. Students must allow for new experiences in order to be truly able to appreciate the scope of the problems on which they will work. The new experiences can also assist in increasing the diversity of their known scope of information; this may help their cognitive processes to make unsuspected links, leading to breakthroughs (Starko, 2014; Forest & Faucheux, 2011). To really gain the most benefit from creativity training, participants must discover their own creative abilities by exploring and developing innate creative skills (Baillie & Walker, 1998; Vzyatishev, 1991).

Intelligence plays only a supportive role in creative skills development. Though there is a link between standardized tests and IQ, there is a very weak interaction between creativity and IQ (Frey & Detterman, 2004; Starko, 2014). One study showed that intelligence and creativity

did in fact suggest a significant relationship ($r = .21$, $p < 0.05$), but the result had only a “small practical significance” (effect size = .04) (Rodrigues Virgolim, 2005). Creativity is only correlated to IQ in that an individual must be sufficiently intelligent (i.e. score above 90) to be creative; this is known as the threshold theory. After the threshold limit, there is little correlation between levels of intelligence and creativity. This means the average person is just as capable of having a breakthrough idea as an intellectual genius.

Project-based creativity enhancement is appearing more and more throughout academia as a tool for creative problem finding and solving (Petty, 1983; Court, 1998; Zhou, 2012). Several studies have demonstrated the use of individual and team project-based work to encourage intrinsic motivation, in order to learn the necessary information to solve a given open-ended problem. It was also found that problem definition plays a significant role in the approach chosen to solve the problem (Lai, Roan, Greenberg, & Yang, 2008). The intention of open-ended problems is to stimulate the individual's inquisitive nature and bring forth a curiosity that is essential to the creative process (Starko, 2014; Forest & Faucheux, 2011). Critical thinking is an essential part of the process and understanding its progression within engineering education provides opportunities for growth.

MIT found it essential to build these creative problem finding and solving skills in their engineering graduates. To accomplish this, they developed the CDIO initiative. The initiative implemented a curriculum tailored to enable engineers "to Conceive, Design, Implement and Operate complex value-added engineering systems in a modern team-based environment" (Badran, 2007). The curriculum states several goals focusing on critical and creative thinking within the context of engineering applications (CDIO Initiative, 2014). The CDIO initiative places great emphasis on problem solving and finding as a means for creative work.

Within this context, a process similar to TRIZ would be applied. TRIZ is based on Russian research into innovation during the Cold War. The process is built upon four main concepts: Situation Analysis, Method of Ideal Result, Systematized Substance-Field Analysis, and the 40 Innovative Principles and Contradiction Table. The process allows for the breakdown of the issues at hand in order to best identify the real problem that needs a solution. It then applies predetermined methods in order to approach and solve the problem. The results of the study show that students found more value in learning within a course focused on TRIZ principles over the traditional teaching method of discipline infusion (Belski, 2009). Though this was perceived as beneficial, the overly structured methodology can also be detrimental to creative problem finding and solving.

Some researchers have determined that creative problem finding and solving are more akin to creative skills than even divergent thinking. The researchers argue that though divergent thinking in fact significantly impacts creative potential, creative problem finding and solving incorporates more aspects of the creative process overall. As a result, it more accurately evaluates the presence and fluctuations of creativity (Plucker, Qian, & Schmalensee, 2014).

Research demonstrates that problem scope and definition largely impact the creative performance of study subjects. In a study by Rietzchel, Nijstad and Stroebe (2014), subjects provided more creative solutions when problem scope and definition were clarified and simplified. The brainstorming undertaken by the subjects improved in creative output when the problem was broken down and defined properly. Additionally, the study also showed strong improvements in creative performance when subjects were asked specifically to give creative answers. This has interesting implications in creativity training, due to the simplicity of requesting creativity from others. The implantation of such a method would be simple to

incorporate into many types of creativity training. When applied properly, creativity training has the potential to provide long-term benefits to the individual, instead of just a post-creativity training spike (Baer, Jr., 1988).

Several studies show that, not only is creativity training effective in increasing creative skill, it is also well-received by the participants. Interviews performed for a study by Zhou reveal that individuals expressed great interest in the ability to develop their creative skills. A student within the study mentioned: "...it is good (that creativity studies are being conducted) because creativity should be the issue in my future work and we need support from teachers" (2012). This is an exceptionally useful finding, as motivation plays a key role in human potential, including creative output (Kouzes & Posner, 2012; Starko, 2014). If students find creativity research and training useful to them, they are more likely to take the training to heart and exercise the tools of creativity.

A literature review on creativity produces studies on many training approaches, as researchers seek to find those which will provide the most impact for individuals. These studies primarily explore creativity training given through seminars or a series of lectures that are relatively short in length, at most a few hours. Some studies such as Clapham's (1997) of short versus longer seminars found that the added time within the seminar training did not significantly improve the benefits of the creativity training. Other studies found that longer-term exposure and reinforcement of the ideas of creativity given over time can actually foster not only a more significant impact on creative potential, but also an increase in retention and possibly application (Gist, 1989; Cropley & Cropley, 2000). This is indicative of an added benefit to longer-term, more in-depth exploration not only of creativity as a subject, but creativity as an application.

Evaluating Creativity

As seen throughout the literature review, creativity is still a primary research topic. Creativity is of great importance to the human condition, as it drives our knowledge acquisition process. As such, it is important both academically and socially to develop ways to evaluate creative skills within individuals, as well as understand how those skills change. Currently, this is accomplished through a myriad of creativity assessments designed to examine the well-known attributes of creative individuals. As mentioned earlier, the Torrance Tests of Creative Thinking are hallmarks in the study of creativity.

The TTCT was designed by J.P. Torrance as an extension of the tests developed for the U.S. Air Force in an attempt to select the best pilots. Torrance noticed the test's ability to show creative skill (creative problem solving and ability to think divergently), so it was modified and used in creativity-based research as well (Starko, 2014). The TTCT evaluates several attributes of creativity, including originality, fluency, elaboration, abstractness of titles and resistance to premature closure. To determine these different attribute scores, the test relies heavily on divergent thinking exercises. Scores for these exercises form the basis of the evaluation scheme of the TTCT, and its determination of the creativity of the individual (Starko, 2014; Root-Bernstein & Root-Bernstein, 2001). The TTCT has become a widely studied and used test of creativity within the K-12 range to determine child giftedness, but also within academic research to test the effectiveness of creativity enhancement techniques.

There is significant research on the applicability and validity of the TTCT in reference to its use within creativity studies. Some argue against its accuracy in determining creative skill on the basis of its heavy reliance on divergent thinking (Zeng, Proctor, & Salvendy, 2011). Though divergent thinking is considered to be an important aspect of creative skill, it is not the only one.

As such, the TTCT, with its emphasis on divergent thinking as an instrument of creative skill, would only give a partial picture of an individual's creative potential. Though this is true, evidence from longitudinal studies conducted on the early subjects of Torrance's test show that it can truly capture much of the future creative skill of tested subjects.

Eminent researchers in the field of creativity performed forty- and fifty-year follow-ups on the original subjects of the TTCT. Cramond et al. (2005) found an adequate correlation between the TTCT's predictions in early life and the later creative personal and public achievements of those same subjects. Specifically, she found that "the predictive validity of the Torrance Tests of Creative Thinking, Verbal and Figural, is relatively strong considering the span of forty years during which time data were collected." The TTCT scores explained 23% of the creative production variance seen within the subjects (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005).

Runco's fifty-year follow-up study concurred with Cramond's findings. He observed that the TTCT's predictions continued to "hold up even over 50 years." An important note from Runco's findings is that participants' results showed the TTCT scores were related specifically to their personal achievements. Runco posited that this could be due to the fact the participants were at an age where personal achievement was more significant than public achievement. This could be due to a reduced need for external validation, and an increase in tasks and goals driven by intrinsic needs and motivation later in life (Runco, Millar, Acar, & Cramond, 2010).

Though the TTCT can provide a measure of creativity in terms of divergent thinking ability, and has been shown by studies to be consistent with long-term creativity as judged by the participants, an approach that is more sensitive to overall creativity is necessary. As discussed, divergent thinking forms an essential but incomplete picture of creative ability (Cropley A. J.,

2000). To this aim, Jellen and Urban (1986) created the Test of Creative Thinking - Drawing Production.

The TCT-DP is based primarily on Carl Rogers' theory of creativity. "Roger's theoretical approach to creativity describes the nature of the creative act, the conditions under which it occurs, and the manner in which it may constructively be fostered." As such, the TCT-DP allows each participant "to create, develop, expand and/or extend something unique or novel that is satisfying to the creator" (Jellen & Bugingo, 1989). This allows for creativity to be witnessed in a less controlled/forced medium, rather than a more rigid construct such as the verbal portions of the TTCT. In addition, the TCT-DP attempts to capture a more complete picture of an individual's creativity (Jellen & Urban, 1986).

The theoretical construct of the TCT-DP is based on the concepts supported by creativity research. The test itself demonstrates internal and construct validity through many studies (Dollinger, Urban, & James, 2004; Cropley & Cropley, 2000; Rodrigues Virgolim, 2005). As such, several researchers have found direct correlations between high test scores on the TCT-DP and high levels of real world creativity (Cropley & Cropley, 2000; Urban, 2004; Jellen & Bugingo, 1989; Leung, 2013; Danial, 2015). Urban (2004) also cites several other studies performed in foreign countries that have similar ties to real world creativity (Togrol, 2012). Based on these studies developed using the TCT-DP, there is strong evidence for the overall reliability and validity of the test as an assessment of creative ability. The TCT-DP is discussed further in the 'Test of Creative Thinking - Drawing Production (TCT-DP)' section in Chapter 3.

Critical Thinking in College

Critical thinking is a vital part of the engineering profession. Engineers are taught to analyze and think through problems from multiple perspectives in order to reach appropriate

solutions. Engineers must design useful items such as alarm clocks and vehicles based on critical requirements, material limitations, cost limitations and many unknowns. Most courses focus on teaching fundamental mathematical concepts and problem solving as a means to teach both engineering, as well as critical thinking in problem solving (Zhou, 2012; Badran, 2007).

Critical thinking is important as a means to analytically solve problems and also as a driver for creativity, it is quite important to understand the effects of the engineering curriculum on the critical thinking skills of undergraduates. Douglas (2012) and Ozyurt and Ozyurt (2015) generally found a stagnation in the critical thinking skills of engineering students. Though this would suggest a potential reduction in critical thinking skills, other studies and assessments (normative data) suggest an improvement in overall critical thinking abilities.

Research largely suggests that critical thinking improves as a result of college experiences, including both coursework and college life. Many studies show strong evidence that the college experiences both academic and extracurricular provide a means of improving critical thinking in college students (Watson & Glaser, 2008; Pascarella, 1987; Keeley S. M., 1992; Spaulding & Kleiner, 1992; Mines, King, Hood, & Wood, 1990; Terenzini, Springer, Pascarella, & Nora, 1995).

According to these studies, by participating in college courses and college life, students experienced a significant improvement in their overall critical thinking abilities. Keeley et al. (1982) found that seniors provided more appropriate critiques of sample passages than freshman participants. Though the researchers noted that the seniors' commentary still lacked some details, the level of critical thinking demonstrated was significantly higher than that of the freshman students. Another study found that, though critical thinking ability was not related to grade level, engineers showed high-level critical thinking skills when tested (Ozyurt & Ozyurt, 2015).

Research has shown that engineers as a group are more likely to have thinking styles inclined towards critical thinking, such as preferring "more highly prioritized thinking" (Gridley, 2007). Additionally, several colleges are actively integrating engineering-based critical thinking instruction within their coursework (Mokhtar, 2010). Since engineers typically focus more on analytically-driven fields such as physics and mathematics, this suggests very positive improvements in critical thinking abilities near the completion of their degrees, through both their experiences and coursework. The large repository of studies suggests that engineers should develop improved critical thinking skills as a result of their engineering education.

Assessing Critical Thinking Skill

Measuring any cognitive trait requires accurate assessment instruments, capable of capturing the trait while resisting pollution from other factors. As a means to measure critical thinking in individuals, the Watson-Glaser Critical Thinking Appraisal Form A provides a consistent and simple means of gathering critical thinking data. The WGCTA Form A Manual details the use of this test on high school students, college students and business professionals. Through its applicability to a wide subset of late teens to adult individuals, the test is acceptable for use in assessing the critical thinking abilities of freshman and senior undergraduates, as conducted in this research. In addition to being age and level appropriate, there is strong evidence of reliability and validity of the test when data is appropriately evaluated and interpreted (Watson & Glaser, 2008; Pascarella, 1987; Mines, King, Hood, & Wood, 1990).

As with all tests used for scientific study, test reliability and validity are essential to successful data interpretation. The WGCTA was used for these experiments based on its extensive history as a reliable and consistent measure of individual critical thinking skills. The WGCTA Form A Manual, as well as additional recent studies, finds good reliability and validity

evaluations in real world studies, as well as good correlation with other known tests of critical thinking (Pascarella, 1987; Behrens, 1996; Gadzella & Baloglu, 2003; Watson & Glaser, 2008; Mines, King, Hood, & Wood, 1990).

Literature Review Summary

This literature review discussed several studies and concepts. There is clear evidence that creativity is in decline, while critical thinking typically increases as a result of the engineering college experience. To provide clarity both for the place of this study within current literature, and how the results of the prior studies reviewed here impacted this research, two summary tables were constructed.

Table 1 categorizes a sampling of the current literature on creativity and critical thinking research discussed within this review. The sample of studies involves only reviewed studies specifically associated with the topics detailed in the table. Other studies were omitted, due to their research topics being ancillary to the topics directly associated with these research questions.

Table 2 provides a summarization of the studies discussed within the literature review. The studies reviewed within this summary are those directly related to the research questions, as well as ancillary studies which provide further support for the conclusions of the direct studies. These summaries provide the essential results and conclusions drawn from the results of other researchers, which drove the inception of this study and its experiments.

The studies discussed herein provide the groundwork for the research questions of this dissertation. Research suggests that creativity is decreasing in engineering students. Further, engineering students appeared to agree with this assertion when asked, as they felt they were not

receiving the instruction needed to maintain their creativity or become more creative. However, critical thinking is on a very different track.

Research suggests critical thinking skills are increasing in students exposed to college experiences, but there are some studies that point toward a stagnation of critical thinking for engineers specifically. Studies by Douglas (2012), and Ozyurt and Ozyurt (2015), suggested that engineering students' critical thinking skills were static. Since these studies focused on students outside of the population being considered, students under different educational framework (Turkey) and graduate students, it is assumed that the general findings from other studies are more relevant; therefore, engineering students are hypothesized to have higher critical thinking abilities after more time spent in college.

Table 1
Literature Review Content Summary and Dissertation Focus

	Birdi, 2005	Clapham & Schuster, 1992	Clapham M. M., 1997	Cropley & Cropley, 2000	Douglas, 2012	Genco, Holtta-Otto, & Conner Seepersad, 2011	Genco, Holtta-Otto, & Conner Seepersad, 2012	Jellen & Bugingo, 1989	Kazerounian & Foley, 2007	Keeley S. M., 1992	Keeley, Browne, & Kreutzer, 1982	Kim, 2011	Mahboub, Portillo, Liu, & Chandraratna, 2004	Mines, King, Hood, & Wood, 1990	Ozyurt & Ozyurt, 2015	Pascarella, 1987	Spaulding & Kleiner, 1992	Terenzini, Springer, Pascarella, & Nora, 1995	Watson & Gaiser, 2008	Weinstein, Clark, DiBartolomeo, & Davis, 2014	Solá	
State of Creativity												X									X	
State of Creativity in Engineers				X		X	X	X														X
State of Creativity between Freshmen and Seniors							X															X
Short-Term Creativity Training	X	X	X			X	X															X
Long-Term Creativity Training				X									X									X
Creativity Training on the General Population	X		X										X									
Creativity Training Effects on Engineers		X		X		X	X						X									X
State of Critical Thinking in Engineers					X									X								X
State of Critical Thinking in College Students										X	X			X		X	X	X	X			
Critical Thinking Evaluation between Freshmen and Seniors											X											X

Table 2
Literature Review Summary of Selected Studies

Authors/Year	Summary of Findings	Relevance to Research
Besnard & Cacitti, 2005	This study aimed to understand the psychological causes behind an accident at a steelworks factory. The study found that unnoticed changes in routine tasks led to errors in input.	Emphasizes the existence of negative transfer and the potentially significant results of the transfer. This may be a significant reason for a decrease of creativity in engineering.
Birdi, 2005	Participants in a two-day creativity training workshop provided by the UK Civil Service reported significant improvements in creativity knowledge, idea generation and implementation of ideas. The study also found that environments with negative feelings towards innovation limited the impact of the training.	The study provides support for creativity training as a functional tool in the improvement of creativity. Additionally, the findings also suggest that environments with negative feelings towards innovation limit the potential benefits of the creativity training.
Cardoso & Baske-Schaub, 2011	The study requested that participants provide new designs for a book retrieval machine for a library. The groups were supplied with sketches (in various levels of detail) of a handheld book retrieval tool. Participants used various aspects directly from the supplied design, often without any real purpose towards creating the solution for the problem.	Emphasizes the existence of negative transfer in engineering design, specifically. This may be a significant reason for a decrease in engineering creativity.
Clapham & Schuster, 1992	This study hypothesized that groups exposed to a one hour creativity training session would have higher creativity scores than groups exposed to one hour of interview skill training. There was significant evidence that the creativity training groups had consistently higher scores than those of the interview training group.	This study result suggests short-term creativity training provides significant benefits to training participants. The focus on engineers provides an additional confirmation that engineers can be trained to improve their creativity.

Clapham, M. M., 1997	<p>The study consisted of a creativity training group, an ideational skills training group and a control group, tested to determine if creativity training (thirty minutes) was more impactful to divergent thinking than ideational skills training (ten minutes). The results showed that creativity training and ideational skills training provided similar improvements in divergent thinking.</p>	<p>Study results suggest that short-term creativity and ideational training may provide significant benefits to training participants. The study focused on divergent thinking improvement; therefore, there are still questions as to the impact on creativity as a whole.</p>
Cropley & Cropley, 2000	<p>A group of engineering undergraduates were provided with three lectures on creativity. A portion of the participants were tested for creativity, and counselled based on the test scores. The counselled students were more innovative six weeks later than those who only received the three lectures with no counseling.</p>	<p>With focused creativity training, the creative skills of engineers can be improved significantly. Additionally, this training is relevant to their real-world production of innovative designs and solutions.</p>
Douglas, 2012	<p>This study explored critical thinking in engineering students. Undergraduate and graduate students were given the California Critical Thinking Skills Test (CCTST) to quantify their critical thinking skills. Douglas found that undergraduate engineers had higher critical thinking scores than graduate engineers. This difference may have been due to the graduate students answering fewer of the questions in the test.</p>	<p>These results suggest that critical thinking may not be changing as a result of engineering coursework. There are limitations to the applicability of the results to the research questions, as the study focuses on the differences between undergraduate juniors and graduate students.</p>

<p>Genco, Holtta-Otto, & Conner Seepersad, 2011</p>	<p>The study found that the use of handicap simulation instruments allowed for the generation of more innovative designs to solve a problem. This method, termed empathic experience design (EED), provides a useful means of creativity training.</p>	<p>Creativity training can benefit engineers in the design of innovative solutions. EED can provide a means for creativity training that is simple to implement.</p>
<p>Genco, Holtta-Otto, & Conner Seepersad, 2012</p>	<p>Freshman and senior engineering students were asked to design a next-generation alarm clock. The teams were split into non-enhanced and enhanced sub groups (four groups total). The study found that the creativity training enhancement provided significant improvements in creative outputs, based on evaluation of their designs.</p>	<p>The study suggests that training can increase creative skill in engineering students. More so, the graph of results suggest that freshman engineering students are more creative than senior engineering students.</p>
<p>Hecht & Proffitt, 1995</p>	<p>To determine the ability of an experienced individual to find the correct solution to a problem within their domain of expertise, researchers asked experienced individuals (bartenders and waitresses) and non-expert individuals (graduate students, bus drivers and housewives) to determine and inscribe the water level on a tilted glass. The results showed that those with experience provided significantly less correct answers than the non-expert individuals.</p>	<p>Subject matter expertise may be detrimental due to negative transfer of knowledge when it is not appropriate. The negative transfer of knowledge may be detrimental to engineering creativity, and may indeed be a reason for the decrease of creativity scores between the freshman and senior students (as suggested by data provided by Genco, Holtta-Otto, & Conner Seepersad, 2012).</p>
<p>Jansson & Smith, 1991</p>	<p>Researchers conducted four experiments asking participants to design a specific tool or item. The participants were provided with sample materials. Participants repeatedly incorporated aspects of the supplied materials that were unnecessary to the function of the item in question.</p>	<p>Design fixation is a very real phenomenon that can be detrimental to creative problem solving in engineers.</p>

Jellen & Bugingo, 1989	The study tested participants of an engineering design-based pentathlon event using the Test for Creative Thinking - Drawing Production (TCT-DP). The test scores correlated very closely with the winners of the pentathlon. The winning designs required extensive creative problem solving and divergent thinking processes.	This emphasizes the face validity and internal reliability of the TCT-DP as a means of evaluating creativity.
Kazerounian & Foley, 2007	A survey asked students and professors how specific Maxims in Creativity were addressed through the engineering coursework. These maxims included learning to fail, leading by example and the search for multiple answers. Engineering students generally felt these creative maxims were largely not addressed within their coursework.	This survey suggests engineering students are not receiving the creativity-focused education necessary to improve their creative skills. The lack of creativity instruction may have a negative effect on their creative abilities.
Keeley, S. M., 1992	Freshman and senior students were asked to critically evaluate two articles in essay form. When the essays were evaluated, seniors consistently provided better criticisms of the articles, but neither group was able to correctly identify implicit assumptions consistently.	The results suggest that senior engineering students should have higher critical thinking skills than freshman engineering students. Results also suggest there is room for improvement in the critical thinking instruction of senior students.
Keeley, Browne, & Kreutzer, 1982	Freshman and senior students were asked to critically evaluate two articles in essay form. When the essays were evaluated, seniors consistently provided better criticisms of the articles, but there were still some deficiencies in the critical evaluations.	The results suggest that senior engineering students should have higher critical thinking skills than freshman engineering students. Results also suggest that there is room for improvement for both groups.

<p>Kim, 2011</p>	<p>This study used normative data from the Torrance Tests of Creative Thinking (TTCT) to develop a statistical assessment of creativity from kindergarten to twelfth grade students. The study found that creativity showed a decreasing trend when observed through the years. Additionally, creativity saw large decreases between fifth grade and the end of high school.</p>	<p>The analysis suggests creativity is decreasing every year, and the progression of students through their coursework may be having negative effects on their creative abilities.</p>
<p>Mahboub, Portillo, Liu, & Chandraratna, 2004</p>	<p>The study implemented a creativity training module within a design-oriented course. The training was taken by both civil engineers and industrial designers. Results suggested that creativity training can support the improvement of creative abilities in both groups.</p>	<p>Though the study did not specify the length of the training, the exercises and length of the course suggest that this training was given over a week or several weeks. Based on the definitions of short-term and long-term training as utilized in this paper, the results suggest that engineering students gain significant benefit from long-term creativity training.</p>
<p>Mines, King, Hood, & Wood, 1990</p>	<p>Groups of freshman, senior and graduate participants were evaluated using the Reflective Judgement interview, Watson-Glaser Critical Thinking Appraisal and Cornell Critical Thinking Test. The most relevant finding to this research was that seniors scored significantly higher than freshman students. When compared to the normative data for the WGCTA, the freshmen scored lower than their equivalent norms, while the seniors scored at the norm average.</p>	<p>The results suggest that college courses have a positive effect on critical thinking skills. As such, engineering students' critical thinking abilities must also be increasing, if not already substantially higher than the general population's scores, due to their subject of study.</p>

Ozyurt & Ozyurt, 2015	<p>The study assessed the critical thinking and problem solving skills of 190 electrical-electronics engineering students through the California Critical Thinking Dispositions Inventory (CCTDI) and the Problem Solving Inventory (PSI) in a college in Turkey. The study found that all students possessed high-level critical thinking skills, though there was no significant difference between grade level and critical thinking scores.</p>	<p>This study suggests engineering students should possess high-level critical thinking scores. It also suggests there may be no improvement between freshman and senior engineers.</p>
Pascarella, 1987	<p>Matched groups of students that did and did not attend the first year of college were assessed before and after the year using the Watson-Glaser Critical Thinking Appraisal. The study found that students with one year of college had significantly higher critical thinking scores than those without college experience.</p>	<p>The results suggest college courses have a positive effect on critical thinking skills. As such, engineering students' critical thinking abilities must also be increasing, if not substantially higher than the general population's scores, due to their subject of study.</p>
Spaulding & Kleiner, 1992	<p>Researchers tested several groups of participants from a range of college grade levels and study areas. The results showed that advanced study is linked to critical thinking skills, as well as high GPAs. There was no evidence that area of study was related to critical thinking scores.</p>	<p>This suggests that the trend observed of increased critical thinking skills through progression in college for other majors is also relevant to engineers. As such, engineers should also follow similar increasing trends in critical thinking abilities.</p>

<p>Terenzini, Springer, Pascarella, & Nora, 1995</p>	<p>The study explored how formal classroom and instructional experiences, curricular exposure and out-of-class experiences affected critical thinking. The study found that both in-class and out-of-class experiences played significant parts in increasing critical thinking. Additionally, time spent studying and the number of unassigned books read also had a positive impact.</p>	<p>This suggests that the trend observed of increased critical thinking skills through progression in college for other majors is also relevant to engineers. As such, engineers should also follow similar increasing trends in critical thinking abilities.</p>
<p>Watson & Glaser, 2008</p>	<p>Normative data for the Watson-Glaser Critical Thinking Appraisal suggests that critical thinking scores increase as a result of college courses. Specifically, the scores for senior-level students are significantly higher than scores for freshman students. This normative data is based on a general college population sample.</p>	<p>The normative data suggests that senior engineering students should have higher critical thinking scores when statistically compared to freshman engineering students.</p>
<p>Weinstein, Clark, DiBartolomeo, & Davis, 2014</p>	<p>This research assessed the creations of a group of creative writers and visual artists. The evaluation led researchers to suggest creativity may not be declining in all domains.</p>	<p>Individuals practicing within traditionally creative fields may not be experiencing the creativity decline seen by other studies. This suggests that the decline in creativity may be focused in fields traditionally thought of as less creative, such as engineering.</p>
<p>Woltz, Gardner, & Bell, 2000</p>	<p>This study found negative transfer to be evident within the context of expert versus non-expert error rates. Additionally, the study revealed that experts executed negative transfer at the "same speed as correct responses to familiar sequence trials" within the study.</p>	<p>Emphasizes the existence of negative transfer and the potentially significant results of the transfer. This may be a significant reason for a decrease in creativity in engineering.</p>

CHAPTER THREE: METHODOLOGY

Experiment 1 Methodology

Experiment 1 investigated the relationship between engineering education and its effects on creativity and critical thinking. Further, the experiment also sought to explore if interactions exist between the critical thinking trends and the creativity trends. A detailed methodology of the experiment follows.

Research Participants

Study participants were recruited from both an introductory course (EGS 1006C, Introduction to the Engineering Profession) and a senior level course in engineering. The participants in the introductory course were first year freshmen in the College of Engineering, and were intended to provide pre-engineering education data regarding their creative and critical thinking capabilities through the testing. Due to the multidisciplinary nature of the introductory course (i.e. multiple engineering majors), the sample is indicative of the base state of creativity and critical thinking in the average incoming engineering student regardless of their field of specialty.

The senior level course students were representative of final year senior undergraduate students. Engineering senior courses are typically department-specific, but capstone courses are typically intermingled with several engineering colleges represented. Participants were randomly requested from the capstone course in order to gather a sample more indicative of the general population, as seen in the introductory course. This allowed for a sample with adequate representation of the education provided in the College of Engineering at the University of Central Florida.

Procedure

Study participants were informed that their participation in the study was completely voluntary, would not have any effect on their coursework, positive or negative, and that they could request removal from the study at any time. Consent forms were distributed, thoroughly discussed and clarified before obtaining verbal consent and continuing with the testing. Participants were not asked for identifiable data. Only age and gender were collected in order to perform demographic analyses. Additionally, participants were notified that if they decided to no longer participate in the study, they could turn in their testing material and it would be destroyed.

After giving consent, study participants completed a test with two distinct parts. The first section was an assessment of creativity through the Test of Creative Thinking - Drawing Production. The TCT-DP used an incomplete drawing as a starting point, and asked study participants to complete the drawing in whatever manner they wished. Their completed drawings were then evaluated based on 11+4 unique factors, which together formed a complete evaluation of the creativity of the individual. The test took a maximum of fifteen minutes for students to complete. Further details on the TCT-DP are covered in the "Test of Creative Thinking - Drawing Production (TCT-DP)" section later in this chapter.

The second section of the testing asked participants to complete the Watson-Glaser Critical Thinking Appraisal. The WGCTA, described in more detail in a later section, provided an assessment of the logical and critical thinking capabilities of the participants. The appraisal assessed critical thinking skills through questions of logic, including inference and the evaluation of arguments. This test required approximately forty minutes to complete.

Both assessments were bundled together as a single testing package and given to participants with sections that collected the necessary identifiers. Assessments of freshman and senior students were administered as similarly as possible within the constraints of testing.

Design

The Experiment 1 study utilized a non-experimental correlational design. The TCT-DP data was analyzed and compared between the two population groups. The same analyses were performed on the WGCTA data. This study tested the relationships between engineering education, critical thinking and creative abilities. Additionally, several other variables were tested for additional effects, such as age and gender.

Statistical Analysis

The Experiment 1 study utilized a non-experimental correlational design. The TCT-DP data was analyzed and compared between the two population groups. The same analyses were performed on the WGCTA data. This study tested the relationships between engineering education, critical thinking and creative abilities. Additionally, several other variables were tested for additional effects, such as age and gender.

$$H_0: \mu_{\text{Freshmen}} - \mu_{\text{Seniors}} = 0$$

$$H_a: \mu_{\text{Freshmen}} - \mu_{\text{Seniors}} > 0$$

The creativity test data gathered through Experiment 1 was analyzed using a Multivariate Analysis of Variance (MANOVA) tests in order to test the above hypothesis. The MANOVAs were evaluated based on a degree of certainty, α , in the 95th percentile. Data determined to be non-normal was analyzed using non-parametric analysis techniques.

The second hypothesis of this experiment was that freshman scores on the critical thinking test would be lower than the scores of seniors. In statistical terms, the experimental hypothesis was:

$$H_0: \mu_{\text{Freshmen}} - \mu_{\text{Seniors}} = 0$$

$$H_a: \mu_{\text{Freshmen}} - \mu_{\text{Seniors}} < 0$$

The critical thinking test data gathered through Experiment 1 was analyzed using a MANOVA test in order to test the above hypothesis. The T-Test was evaluated based on a degree of certainty, α , in the 95th percentile. Data determined to be non-normal was analyzed using non-parametric analysis techniques.

The MANOVA analysis includes comparative analyses for the sub scores of both the TCT-DP and the WGCTA. The comparative analyses were conducted in order to determine which sub scores were significantly affected by the independent variable: time spent in the engineering curriculum.

Experiment 2 Methodology

Experiment 2 explored the relationship between short-term and long-term creativity training. Both treatment groups were exposed to different lengths of creativity training and given a test of creativity (the TCT-DP) before and after the treatment. A detailed methodology of the experiment follows.

Research Participants

Study participants were recruited from an undergraduate engineering leadership course and an undergraduate capstone course. Potential participants in both courses were within their last year before completion of their degree. The seniors undertaking the creativity course were

multidisciplinary in nature due to the wide range of the course content. This allowed for a sample with adequate representation of the education provided in the College of Engineering at the University of Central Florida.

Procedure

Study participants were informed that their participation in the study was completely voluntary, would not have any effect on their coursework, positive or negative, and that they could request removal from the study at any time. Consent forms were distributed, thoroughly discussed and clarified before obtaining verbal consent and continuing with the testing. Participants were not asked for identifiable data. Only age and gender were collected to in order to perform demographic analyses. Additionally, participants were notified that if they decided to no longer participate in the study, they could turn in their testing material and it would be destroyed.

After consent was given, creativity course study participants were administered the TCT-DP Form A as a pre-test; this group is referred to as CA in the results section. The pre-test was given approximately six weeks after the beginning of the overall leadership course (EGS 4624, Engineering Leadership and Innovation). The delay in testing was due to a delay in study materials delivery. No creativity training was given during the six weeks, but the same professor who was to teach the later creativity portion taught the leadership portion first during the six-week gap. On the last scheduled day of the creativity training portion of the course, the TCT-DP Form B was administered as a post-test; these group results are referred to as CB in the results section. Both pre- and post-tests are equivalent based on the TCT-DP. The TCT-DP is distributed

in two forms, A and B, in order to prevent re-test bias among the participants when taking the test the second time.

Participants enrolled in the capstone course were asked to participate in the study. This group of seniors constituted the workshop group (i.e. short-term training). As part of standard practice within the course, a portion of the capstone course students were required to attend creativity training in the form of a one and one half hour training workshop. Students were not informed of which study group they were participants.

Participants assigned to the workshop training group were given the first form of the creativity test, TCT-DP Form A, before being provided with one to two hours of creativity training; this group is referred to as WA in the results section. After the end of the workshop, the TCT-DP Form B was given as a post-test. The TCT-DP is distributed in two forms, A and B, in order to prevent re-test bias.

Design

The Experiment 2 study used an experimental comparative correlational design, using data where participants' responses were weighed on a scale of creativity as defined by the TCT-DP and compared across two treatment groups. The independent variable in this study was the creativity training instruction duration; the dependent variable was the creativity score as determined by the TCT-DP. This study determined the impact of creativity training duration on creative skill, as measured by the TCT-DP. Additionally, several other variables were examined for interaction effects, such as age and gender.

Statistical Analysis

The hypothesis of this experiment was that the mean difference of scores from the creativity course group would be greater than the mean from the creativity workshop group. In statistical terms, the experimental hypothesis was:

$$H_0: \mu_{CC} = \mu_{Workshop}$$

$$H_a: \mu_{CC} > \mu_{Workshop}$$

Data collected through the TCT-DP was analyzed using MANOVA tests. The analyses were evaluated based on a degree of certainty, α , in the 95th percentile. The data being considered was that of the pre-test and post-test conditions for the creativity course participants, and of the workshop-trained participants. A repeated measures MANOVA was used to determine whether the long-term training group's creativity scores improved significantly above that of the short-term group. In statistical terms, the experimental hypothesis was:

$$H_0: \mu_{TCT-DP/Post-Test} - \mu_{TCT-DP/Pre-Test} = 0$$

$$H_a: \mu_{TCT-DP/Post-Test} - \mu_{TCT-DP/Pre-Test} > 0$$

The analysis was evaluated based on a degree of certainty, α , in the 95th percentile. The analysis determined whether the training had a significant effect on the participants.

The MANOVA analysis includes comparative analyses for the sub scores of the TCT-DP for all groups. The comparative analyses were conducted in order to determine which sub scores were significantly affected by the independent variable, creativity training duration.

Assessment of Creativity and Critical Thinking

Test of Creative Thinking - Drawing Production (TCT-DP)

In order to quantitatively evaluate the creative skill of individuals, a creativity test must be used. The standard in creativity assessment tests is the Torrance Tests of Creative Thinking (Torrance, 1988; Kim, 2011). As stated in the literature review, the TTCT has very thorough evaluation through a large subset of studies. The TTCT has been found to have proven validity, as well as some longitudinal studies with data demonstrating long-term verification of real world creative output among those who scored highly (Cramond, Matthews-Morgan, Bandalos, & Zuo, 2005; Runco, Millar, Acar, & Cramond, 2010; Ibrahim, 2012).

Even with this level of evaluation, researchers find fault in the results of the TTCT. The TTCT focuses primarily on divergent thinking tasks as the basis of evaluating creativity. Though divergent thinking is a portion of creativity, it is not a complete evaluation of creativity (Cropley A. J., 2000). As such, other tests have been developed intending to more fully evaluate the multiple aspects of creative thinking.

Due to the shortcomings inherent in the TTCT and other available tests of creativity, Jellen and Urban developed a creativity assessment capable of measuring a set of criteria inherent in the creative individual. The Test of Creative Thinking - Drawing Production is designed to be capable of measuring creative ability regardless of age or culture. The TCT-DP construct is supported through existing literature on creativity, including such hallmarks of creativity as fluency, flexibility, originality and elaboration, much like the TTCT. Additionally, risk-taking, composition and humor were also included as abilities inherent in creative individuals (Jellen & Urban, 1986; Urban, 2004).

The test consists of a square containing several non-specific shapes. The participant is asked to complete the drawing in any way they see fit. Different approaches to the given task are then evaluated based on the 11+4 criteria that make up the TCT-DP test. Figure 5 shows a completed TCT-DP assessment produced by a participant of this study.

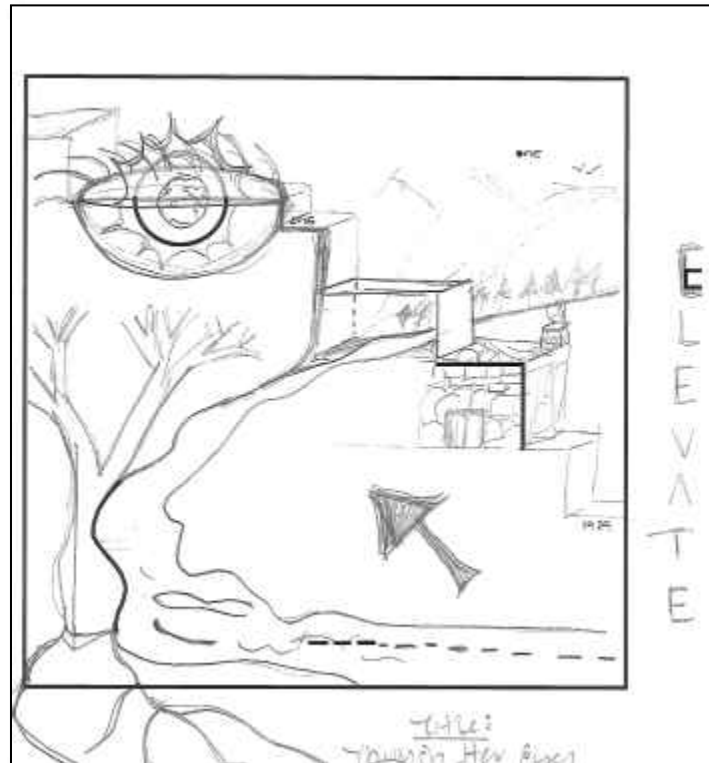


Figure 5: Completed TCT-DP Sample from the Study

The TCT-DP evaluates creative ability with the use of 11+4 criteria developed as a complete analysis of an individual's creativity through Continuations (Cn), Completions (Cm), New Elements (Ne), Connections made with a line (Cl), Connections made to produce a theme (Cth), Boundary breaking that is fragment dependent (Bfd), Boundary breaking that is fragment independent (Bfi), Perspective (Pe), Humor and affectivity (Hu), Unconventionality, a (Uc, a), Unconventionality, b (Uc, b), Unconventionality, c (Uc, c), Unconventionality, d (Uc, d), and

Speed (Sp). Speed was not used as a measure within the analyses due to the limitations imposed by participant testing.

Creativity is defined in many ways, depending on the text or assessment being used. Traditional creativity measures are focused on divergent thinking as one of the more important measures of creativity. These include aspects such as fluency, elaboration, flexibility and originality. Since traditional tests are mainly focused on divergent thinking, some of the more whole-picture creativity measures set forth in the TCT-DP do not have direct links to the traditional measures. As such, Jellen and Bugingo (1989) developed a table that linked the TCT-DP measures to traditional measures of creativity, and provided possible new measures for those without direct links to traditional research measures. Using this table and current creativity research as a reference, Table 3 provides a synopsis of the TCT-DP variables, associated mental processes and their links to traditional and current creativity research. The new measures are interesting, as they reference the characteristics of creative individuals, such as risk-taking and sensitivity (Starko, 2014). This allowed for a starting point to map the existing creativity course against the testing criteria. The mapping shows that the course content is not training to the test; instead, the test only quantifies the impact the training has on the students. Through the use of the TCT-DP, the creative ability of an individual is measured through the interactions of the multiple variables into a "Gestalt" composition, or complete whole.

Table 3
Links and Definitions for TCT-DP Measures

Mental Processes	TCT-DP Variables	TCT-DP Variables	Measures Linked to Research	General Definition
Convergent Thinking	<u>Cn</u>	Continuations	Fluency ¹	Ability to generate many ideas
	<u>Cm</u>	Completions	Elaboration	Ability to add to ideas to improve them
	<u>Cl</u>	Connections made with Lines	Flexibility	Ability to generate different types of ideas or ideas from multiple perspectives
	<u>Pe</u>	Perspective	Elaboration	Ability to add to ideas to improve them
Divergent Thinking	<u>Ne</u>	New Elements	Originality	Ability to generate novel ideas
	<u>Uca</u>	Unconventionality A	Curiosity ² (Traditionally Flexibility)	Need to explore and understand the known and unknown
	<u>Ucb</u>	Unconventionality B	Originality	Ability to generate novel ideas
	<u>Ucd</u>	Unconventionality C	Originality	Ability to generate novel ideas
	<u>Cth</u>	Connections made to produce a Theme	Synthesis ²	Ability to coalesce multiple ideas into one
	<u>Bfd</u>	Boundary Breaking Fragment Dependent	Detectability ²	Ability to detect changes, cues and patterns within problem
Affections	Hu	Humor	Sensitivity ²	Capacity for emotional transference
	Ucc	Unconventionality C	Passion ²	Ability to express concepts important to the individual
Volitions	Bfi	Boundary Breaking Fragment Independent	Risk ²	Ability to take action in the face of the unknown

¹ Though Jellen and Bugingo (1989) categorized fluency under convergent thinking, a review of literature suggests it should be categorized instead under the divergent thinking process, as the ability to generate many ideas is a cornerstone of divergent thinking.

² Not traditional measures in the evaluation of creativity within the research, but suggested as new measures for creativity measurement by Jellen and Bugingo (1989). Definitions have been generated by the researcher with reference to measurement intent and literature referring to these characteristics of creative individuals (Starko, 2014; Andreasen, 2006; Root-Bernstein & Root-Bernstein, 2001).

To understand how the existing creativity training given in both the course and the workshop supported the learning necessary to improve creative skills, the course content was mapped against the test criteria. Table 4 shows the mapping of the TCT-DP measured variable, the individual trait with which it was associated, and the existing course content which supported that individual creative trait. The course content was originally designed specifically to support the individual traits and concepts of creativity. The connection to the TCT-DP measured variables portrays only how the test captured any improvements. In no way was the course "taught to the test," as only pre-existing content was taught and not any additional material specific to the TCT-DP information.

Table 4
Creativity Trait and Course Content Mapping

Measured TCT-DP Variable	Associated Creative Individual Traits	Existing Course Content Supporting Individual Traits
Boundary breaking that is fragment dependent (Bfd) Boundary breaking that is fragment independent (Bfi)	Risk-Taking	Classroom environment and readings
Humor and affectivity (Hu)	Sensitivity, Playfulness	Classroom Environment, Storytelling and Beach Project Group Deep Dive
Connections made with a line (Cl) Connections made to produce a theme (Cth)	Synthesis, Flexibility, Convergent Thinking	Deep Dive Synthesis Session
New Elements (Ne)	Originality	Impressionist art activities and learning
Unconventionality (a-d)	Openness to Experience, Originality, Non Conformity, Synthesis & Detectability	Beach Project Ideas Requirements (30 Ideas requirement elicits wild and novel ideas due to the amount necessary)
Completions (Cm)	Tolerance of Ambiguity, Perseverance, Logical Thinking	Beach Project (Loosely Bounded Problem with large number of possibilities)
Continuations (Cn)	Comprehension, Fluency	Classroom Environment, Storytelling and Beach Project Group Deep Dive
Perspective (Pe)	Visualization	Explored through readings and discussions

The theoretical construct of the TCT-DP is based on research-supported concepts of creativity. Further, the test itself has shown validity through many studies. Several research studies have found direct correlation between high test scores on the TCT-DP and high levels of real world creativity (Cropley & Cropley, 2000; Urban, 2004; Jellen & Bugingo, 1989; Dollinger, Urban, & James, 2004; Leung, 2013; Ibrahim, 2012). Urban (2004) also cites several other studies performed in foreign countries that had similar ties to real world creativity (Togrol, 2012). Based on these studies developed using the TCT-DP, there is strong evidence for the overall reliability and validity of the test as an assessment of creative ability.

In addition to the validity of the combined scores calculated through the evaluation of the creativity measures, several studies suggest that the individual creativity measures also provide a more specific evaluation of creative characteristics within individuals. Jellen and Bugingo (1989) compared TCT-DP sub scores to real world engineering designs created by competition participants. High sub scores in Uca, Ucb, Ucc and Ucd, which focus on risk-taking and non-conforming thinking styles, correlated closely with the winners, who were evaluated on the innovativeness and originality of their designs.

Cropley and Cropley (2000) utilized a more in-depth statistical application of the sub scores. The researchers used a pre-test of the TCT-DP to determine lacking areas of creativity in an experimental group using a factor analysis of the sub scores. These were used to individually train students in their lower areas of creativity, as defined by the TCT-DP. Finally, the pre- and post-training sub scores were statistically analyzed, suggesting certain sub scores (creative characteristics) showed no statistically significant increase, while others showed significant improvement as a result of creativity lectures and one-on-one creativity counseling of the

students. Dollinger et al. (2004) also used the sub scores to determine how specific creativity characteristics were affected.

Based on these studies, the TCT-DP sub scores can provide a more in-depth analysis of which factors or sub scores of creativity are declining, increasing or remaining stagnant. As such, participant creativity analyses can shed light on not only whether one group shows better performance, but which aspects of creativity are showing the better performance. This may lead to insights as to which aspects of creativity are being affected most by experimental variables or external environmental variables.

Critical Thinking Test

Engineering education typically focuses on training students to think critically about a given problem, in order to forge solutions from experience and learned concepts. This is vitally necessary for any engineer to be able to function within the realm of laws that govern physics and mathematics. Critical thinking is also an essential part of the creative thinking process, specifically in the process of synthesis (Starko, 2014; Root-Bernstein & Root-Bernstein, 2001; Andreasen, 2006). Based on this, Experiment 1 postulated that the critical thinking abilities of senior engineering students would be superior to those of the freshman engineering students, due to the intensive coursework intended to hone their critical thinking skills (i.e. analysis, synthesis, etc.). To measure the differences between their levels of critical thinking ability, the Watson-Glaser Critical Thinking Appraisal Form A was used.

As a means to measure critical thinking in individuals within this study, the Watson-Glaser Critical Thinking Appraisal Form A provides a consistent and simple means of measuring critical thinking skill in a wide range of individuals. The WGCTA Form A Manual details the

use of this test on high school students, college students and business professionals. As such, the test is acceptable for use in assessing the critical thinking abilities of freshman and senior undergraduates.

As mentioned earlier, the WGCTA has a history of scientific study, test reliability and validity. The WGCTA Form A Manual, as well as additional recent studies, finds good reliability and validity evaluations in real world studies, as well as good correlation with other known tests of critical thinking (Pascarella, 1987; Behrens, 1996; Gadzella & Baloglu, 2003; Watson & Glaser, 2008; Mines, King, Hood, & Wood, 1990). The test is in a standard multiple choice format with eighty questions and take no more than forty minutes to complete. The answer key provided a simple and minimally error-prone approach to grading and gathering data.

Experimental Validity and Controls

Workshop Duration and Teaching Constraints

Creativity training is an extensive topic. Many components must be covered at different levels of detail in order to obtain the desired results. The general sections typically covered within the creativity course were the same as those covered during the workshop. To accommodate the reduction in duration, much of the additional depth of the content was removed. Figure 6 shows a sample layout for the creativity course. Figure 7 shows a sample of the workshop training agenda.

- **Creativity and the Brain**
 - Brain Plasticity and Ability to Improve Creative Output
 - Little c vs. Big C Creativity
- **Characteristics and Tools of Creative Thinking**
 - Characteristics of Creative People
 - Additional Readings
- **Divergent Thinking**
 - Multitude of Ideas
 - Thinking Beyond the Standard Applications
- **Group Creativity**
 - Pitfalls of Group Creativity
 - Ways to Avoid Group Creativity Pitfalls
- **Divergent Thinking Exercises**
 - How 30 Circle Exercise
- **Design Thinking Exercises**
 - Alarm Clock Design
 - Design Flaws in Real World Products
- **Creative Thinking Examples**
 - Surgery Glove Example
 - Shale Oil Example

Figure 6: Sample Creativity Course Curriculum

- **Creativity and the Brain**
 - Brain Plasticity and Ability to Improve Creative Output
 - Little c vs. Big C Creativity
- **Characteristics and Tools of Creative Thinking**
 - Characteristics of Creative People
- **Divergent Thinking**
 - Multitude of Ideas
 - Thinking Beyond the Standard Applications
- **Group Creativity**
- **Divergent Thinking Exercises**
 - 30 Circles Exercise

Figure 7: Sample Creativity Workshop Curriculum

It was essential that similar underlying topics of creativity were taught in both types of training sessions. Based on the similarity of training content, the differences in creative skills were then attributable to the difference in length and depth of the creativity training between the course and the workshop.

Confounding Effects

Within human-based testing, many effects cannot be controlled. Humans are intricate beings with many dimensions of complexity, which are impossible to fully measure or understand. As such, many confounding effects are present in studies with human subject trials. These confounding effects must be determined and mitigated where possible.

Some confounding factors are impossible to quantify and consider as a factor in the evaluation of human behavior. Historical experiences, learning abilities, determination, and other character and historical traits of individuals play a large role in their acceptance and retention of training, as well as their abilities to act on the concepts learned. These are confounding effects that cannot be quantified. The only mitigation to these individualized effects lies in the size of the samples. With large enough sample sizes, these individual effects subside and the effects of the independent variable will instead be predominant.

One further confounding effect is the population being tested to derive conclusions. The creativity training portion of the experiments required the use of two different sample populations in order to determine how senior engineering students were affected by creativity training. The creativity course senior engineering students (CA/CB) and the creativity workshop senior engineering students (WA/WB) were recruited for the study from different courses at different times. These differences confounded the results, but the variations between the two were limited by the use of a pre-test and post-test. This allowed for each group to be evaluated against itself.

The testing environment for these two groups also confounded the data. The creativity course senior engineering student testing was tightly controlled, due to the tests' incorporation

into the class schedule. The creativity workshop senior engineering student testing was held during a “boot camp”-style training course that covered a wide variety of topics. The testing was held before the workshop actually began and during a break after the training. The rather hectic environment may have affected the students’ responses.

The freshman engineering students also confounded the study. As the freshman engineering students were still at a point where they could change from engineering into other majors, the data collected could not completely match the data collected from the senior engineering students with whom they were compared. Since freshman students may either exit or complete the engineering curriculum, this study limited the confounding effects by accepting both outcomes, and posing conclusions based on both outcomes. Freshman students were also given a leadership and introduction to engineering lecture by the same professor who taught the creativity course. Though no specific creativity training took place during this lecture, it is possible that the professor’s teaching style might have influenced the creativity of the freshman engineering students.

Some confounding effects are possible to control. Participants were asked to avoid non-course-related creativity training, and not divulge course content to students outside the course. By preventing the disclosure of course content to outside students, the validity of the other study groups (i.e. creativity course and workshop participants) could stay intact throughout the training and evaluation processes.

Additionally, body language and the wording of the instructions given during administration of the test could potentially influence the participants. To mitigate the possibility of multiple approaches to administering the testing material, the researcher developed a standard set of instructions to be given, in order to maintain a level consistency between testing

administrations. This confounding effect is discussed further in the Instrument Change Bias section.

Selection Bias

Bias based on selection of study participants was another means of introducing erroneous data into the study. Participants who were asked to participate were from existing courses whose populations were based on the students' own course preferences. This allowed for an adequately random sample within the College of Engineering. At no time were participants purged from the results unless it was requested by a participant who no longer wished to be part of the study.

Test Equivalency and Retesting Bias

The TCT-DP testing forms are available in two distinct versions: Form A and Form B. "Form B is an inversion of Form A" (Dollinger, Urban, & James, 2004). As such, these two forms were developed in order to mitigate re-testing bias by providing an equivalent but non-identical post-test for comparative experimental and non-experimental designs. For the senior group participants who were tested before and after their creativity training, the pre-testing groups were given Form A, while the post-testing groups were given Form B. The freshman group for the purposes of Experiment 1 was only tested one time, using Form A, in order to compare their results with those of the senior group.

Researcher and Evaluator Bias

Researcher expectations are an ever-present form of bias in any given experiment. As such, steps were taken in order to minimize the introduction of biases in the evaluation of subjective tests such as the TCT-DP. To minimize this bias, the advising professor and two

graduate students not directly associated with the study or the testing were thoroughly trained to evaluate the completed TCT-DP tests using the instruction provided in the official manual (Urban & Jellen, 2010). The manual reports inter-rater reliabilities, along with trained raters, exceeding .90. After training, the graduate students were given several completed tests to evaluate, available through the manual, and their independent scores were correlated using the Intraclass Correlations Coefficient (ICC) as there were only three raters (Shrout & Fleiss, 1979; McGraw & Wong, 1996). Without inter-rater agreement of subjective evaluations, the validity of the results and conclusions may have been subject to questioning. Inter-rater correlation through the use of the ICC provides a measured way to determine the scoring agreement between the raters. The ICC was calculated for each study group.

With the inter-rater correlation assessed, the evaluations given by the raters could then be effectively used for the subsequent statistical tests. To ensure that experimenter and rater bias was mitigated, the completed tests were organized in order to conduct a blind evaluation of the data. Each of the raters was given a full set of completely randomized and unmarked digital copies of the completed TCT-DP tests. Only the researcher was aware of which tests belonged to which group. Raters were not provided with this information until after all tests were evaluated and reported.

After an initial evaluation, a large delta was found in the data between the raters. As such, a secondary training session was conducted in order to realign the expectations for the different sub scores. The alignment only clarified the intent of each sub score between the raters, in order for the raters to grade the same drawings in a similar manner. No additional information or biases were introduced during this second session, as the raters were only asked to clarify the meanings of the sub scores with each other.

Instrument Change Bias

Since creativity is a psychological phenomenon, variations in testing instruction delivery could affect the results of the testing. Though the instruments of evaluation were not changed between sampling tests, the presentation of the content could influence the manner in which participants approached the testing. As a control to this possible influence on the dependent variable, a set of instructions was prepared and is replicated below. The instructions were intended to provide participants with the exact same information, regardless of the study group or condition with which they were involved. Figure 8 and Figure 9 show the scripted instructions for Experiments 1 and 2, respectively. Though there are no specified directions for the Watson-Glaser Critical Thinking Appraisal in the instructions seen in the figures, the manual contains a detailed test administration monologue to achieve the same goal of continuity between administrations. The instructions below are intended to remind participants of their rights as participants and introduce the overall testing format and length.

Thank you for volunteering to participate in this research study. Participation in this study is not required for completion of this or any course. Your participation, or lack of participation, will have no effect on your course assignments or grades. Please remember your participation in this study is completely voluntary and you may decide to discontinue your participation at any time. Should you ask to be removed; all personal information and data gathered will be destroyed as a safeguard to privacy. For those that participate through the duration, please know that all collected personal information and data will be secured for use for the purposes of this research.

You will be given a test that will last approximately 50 minutes. The test may be completed at any time within the allotted time. The first section of the test will be a free drawing section. Please do not be concerned with drawing ability as it has no effect on the evaluation of the drawings. Complete the drawing any way you wish to complete it.

Once complete, please look at the board and write whatever symbol is written on it on the front of the testing material. After completing this step, please stay seated and wait for the completion of the rest of the study participants. Do not proceed to the second section until you are instructed to do so after everyone has completed the first section.

The second section of the test is a multiple choice format assessment. Please make sure to read the questions and answers completely before answering the questions. More instruction will be given when the second section is being administered.

If you have any questions, please feel free to ask at any time before, during or after the testing. Thank you for your participation in this study.

Figure 8: Sample Test Administration Instructions for Experiment 1

Thank you for volunteering to participate in this research study. Participation in this study is not required for completion of this or any course. Your participation, or lack of participation, will have no effect on your course assignments or grades. Please remember your participation in this study is completely voluntary and you may decide to discontinue your participation at any time. Should you ask to be removed, all information and data gathered will be destroyed as a safeguard to privacy. For those that participate through the duration, please know that all collected information and data will be secured for use for the purposes of this research.

You will be given a test that will last approximately 15 minutes. The test may be completed at any time within the allotted time. The test is based on free drawing. Please do not be concerned with drawing ability as it has no effect on the evaluation of the drawings. Complete the drawing any way you wish to complete it.

Once complete, please look at the board and write whatever symbol is written on it on the front of the testing material. After completing this step, please stay seated and wait for the completion of the rest of the study participants.

If you have any questions, please feel free to ask at any time before, during or after the testing. Thank you for your participation in this study.

Figure 9: Sample Test Administration Instructions for Experiment 2

CHAPTER FOUR: RESULTS

Overview

This chapter presents the results of both experiments considered within this dissertation. Quantitative statistical analyses were used to determine significant differences between sample data from the various groups tested. The evaluation of the TCT-DP was also explored in terms of inter-rater reliability and rater background.

In addition to the testing data gathered during the administration of the tests, demographic data was collected to further understand each sample. The demographic details of the participants are covered more in depth in a following section. These results detail relationships between age, gender, creativity scores and critical thinking scores.

The results presented were calculated based on the hypotheses discussed in Chapter 3. SPSS Version 24 was used as the statistical software for all calculations in this chapter (IBM Corp., Released 2015). Where the results deviated from the hypotheses, additional statistical tests were conducted to determine the true inclinations of the data.

TCT– DP Evaluation and Agreement

All of the TCT-DP tests were evaluated by each of the three raters. These raters included the dissertation advisor, an associate professor in the College of Engineering, and two graduate students. The sample of raters provided a wide range of perspectives for the evaluation of creativity. The TCT-DP suggests that the test is consistent across many ages and cultural differences. The Intraclass Correlation Coefficient was calculated for the raters' combined scores to determine the degree of agreement between the raters. Each testing group's data was evaluated using a two-way random effects model to calculate the ICC. The two-way random effects model

could be used as the evaluation had a consistent set of raters, and the raters were randomly chosen from a pool of possible raters (i.e. other graduate students).

Both single measure and average measure ICCs were reported. The average measures report the overall agreement between the three raters who scored the tests for the studies covered in this dissertation. The overall agreement of the raters directly lends validity to the results of the study. The single measures detail the rater reliability expected of the TCT-DP based on the provided rating instructions.

The single measures ICC results for the freshman participants ($ICC_{FA, SM} = 0.811$), pre-training creativity course seniors ($ICC_{CA, SM} = 0.866$), post-training creativity course seniors ($ICC_{CB, SM} = 0.860$), pre-training workshop seniors ($ICC_{WA, SM} = 0.877$) and post-training workshop seniors ($ICC_{WB, SM} = 0.859$) show almost perfect agreement between raters ($ICC > .80$). The average measures ICC results for the freshman participants ($ICC_{FA, AM} = 0.928$), pre-training creativity course seniors ($ICC_{CA, AM} = 0.951$), post-training creativity course seniors ($ICC_{CB, AM} = 0.949$), pre-training workshop seniors ($ICC_{WA, AM} = 0.955$) and post-training workshop seniors ($ICC_{WB, AM} = 0.948$) also showed almost perfect agreement between raters ($ICC > .80$). This provides strong evidence of consistency and agreement between the three raters.

The raters represented a diverse sample for the evaluation of a creativity test. Raters were respectively from the United States of America, Columbia and India, and included two males and one female. These results and demographics point to the TCT-DP as being a truly multicultural tool of creativity, as the ratings maintain consistency and agreement under multiple world perspectives.

Based on these statistics, the study data is sufficiently robust to draw conclusions from the results. Additionally, the broad age range and multi-cultural characteristics of the raters

allows for further validation of the TCT-DP. As demonstrated through these results, the TCT-DP is a robust tool for creative skill measurement with application across age and cultural lines.

Statistical Considerations

Based on the evidence presented regarding the level of agreement between the TCT-DP raters, the evaluated scores were averaged together. The averaging of the scores provided a single data set to perform the various statistical tests needed. To ensure that the assumptions of statistical tests were reasonably addressed, the Shapiro-Wilk test was conducted on each of the five data sets for the TCT-DP: freshman engineering students (FA), pre-training creativity course senior engineering students (CA), post-training creativity course senior engineering students (CB), pre-training workshop senior engineering students (WA), and post-training workshop senior engineering students (WB). The WGCTA scores were also evaluated using this normality test in order to ensure their compliance with statistical assumptions.

All data samples were analyzed for normality to determine the applicability of statistical tools with assumptions of data normality. The Shapiro-Wilk normality test was chosen based on its proven ability to work successfully in a wide variety of situations (Razali & Wah, 2011; Yap & Sim, 2011). Several data samples were found to potentially violate the normality assumptions of the T-Tests and ANOVA analyses used to produce the results. Based on this information, a more thorough analysis of the normality of the data was conducted. This section addresses the potential deviations from normality in the data and proposes the solution going forward.

Two potentially non-normal data samples were found from the averaged TCT-DP scores. The first sample group evaluation in question was the post-training creativity course seniors (CB) ($W = 0.971$, $P\text{-Value} = 0.019$). Additionally, the pre-training creativity course seniors' (CA) WGCTA scores were also found to be non-normal based on the Shapiro-Wilk normality

test. Figure 10 and Figure 11 show the normal plots for the post-training creativity course seniors' (CB) TCT-DP scores and pre-training creativity course seniors' (CA) WGCTA scores.

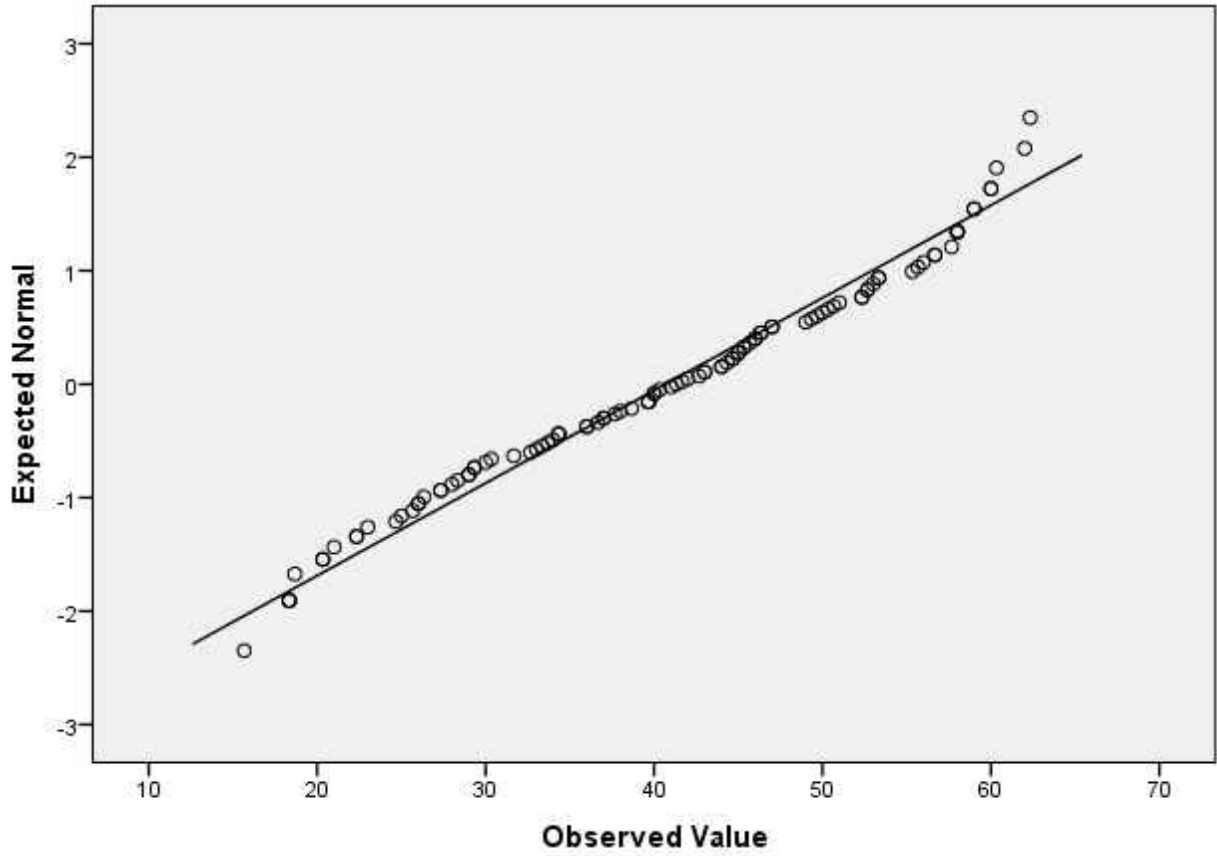


Figure 10: Normal Q-Q Plot for Post-Training Creativity Course Seniors (CB) for TCT-DP scores

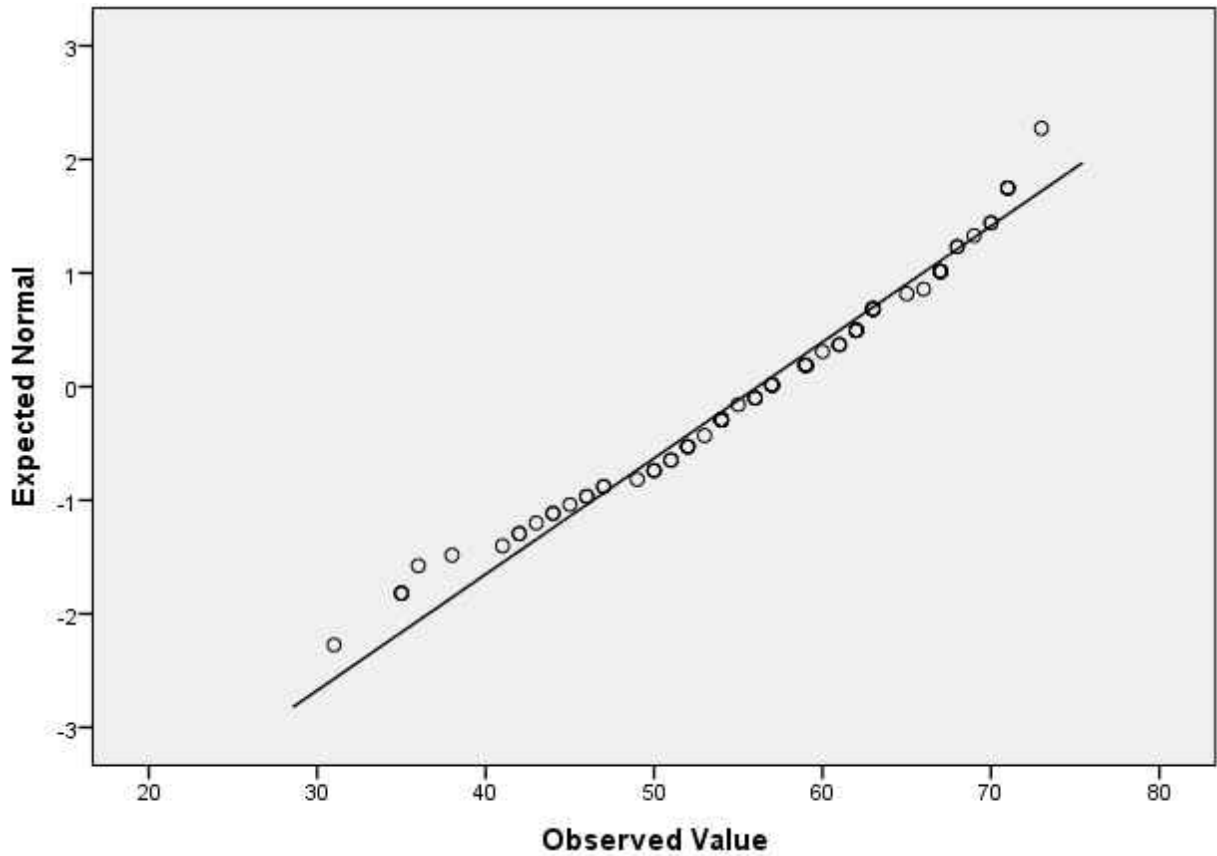


Figure 11: Normal Q-Q Plot for Pre-Training Creativity Course Seniors (CA) for WGCTA scores

Though the participant samples for the evaluation sets in question were large enough ($N > 60$) to assume that the gathered data was normal based on the Central Limit Theorem, the deviations were evaluated using both parametric and non-parametric statistical tools. Analyses involving the non-normal evaluation sets detailed in this section were analyzed using the Mann-Whitney U Test. By using these methods, the non-normality of the samples discussed in this section was addressed two-fold for a clearer understanding of the results.

Participant Demographics

Participants were instructed to provide gender and age information at the commencement of all testing. Participants consisted of freshman students from EGS 1006C (Introduction to the Engineering Profession), senior students from EGS 4624 (Engineering Leadership and Innovation) and engineering senior students participating in a creativity workshop as part of a capstone course. All participants volunteered to take the TCT-DP. A portion of the EGS 4624 and EGS 1006C students were offered the opportunity to participate in the WGCTA testing as well. One hundred twelve senior engineering students from the EGS 4624 volunteered to take the TCT-DP ($n_{CA} = 112$). Of these EGS 4624 students in the creativity course, 105 participated in the TCT-DP post-testing ($n_{CB} = 105$). Sixty-two freshman engineering students volunteered to participate in the TCT-DP testing from the EGS 1006C course ($n_{FA} = 62$). Sixty-eight creativity workshop senior engineering students from the capstone course volunteered to participate ($n_{WA} = 68$). Of this sample of creativity workshop seniors, 65 volunteered to participate in the TCT-DP post-testing ($n_{WB} = 65$). The following results are based on the data provided by these groups.

Though instructions were given before the testing to provide gender and age on the TCT-DP forms, some participants did not provide the necessary information. As such, the gender and age analysis of the data was limited to the participant data for which the demographic information was provided. For analysis requiring age, all individual data not containing gender information was excluded from the sample. For analysis requiring both, all participant data without gender and age information was excluded for the purposes of that specific analysis. No evaluations were found that omitted gender but provided age; therefore, no data was removed for gender alone. Table 5 provides details regarding the excluded data. It is important to restate that the data was only excluded on the specific analyses that required gender and/or age; other

analyses which only required TCT-DP or WGCTA score data were evaluated with all available data.

Table 5
Data Removed from Gender and Age Analyses Due to Unavailability

Group	Gender	Age	Both
CA	0	5	0
CB	0	6	16
FA	0	0	0
WA	0	8	4
WB	0	2	22

The Gestalt, or combined, scores for the TCT-DP were analyzed using age and gender influencing factors. Of the freshman introductory course participants involved in testing of the TCT-DP (FA), 38 were male freshmen ($n_{FA, Males} = 38$) and 24 were female freshmen ($n_{FA, Females} = 24$). Of the creativity course senior participants involved in pre-training testing of the TCT-DP (CA), 87 were male seniors ($n_{CA, Males} = 87$) and 25 were female seniors ($n_{CA, Females} = 25$). The post-training creativity course senior engineering student group (CB) consisted of 63 male seniors ($n_{CB, Males} = 63$) and 20 female seniors ($n_{CB, Females} = 20$). Pre-training creativity workshop senior engineering students (WA) consisted of 43 male seniors ($n_{WA, Males} = 43$) and 17 female seniors ($n_{WA, Females} = 17$). The post-training creativity workshop senior engineering student group (WB) consisted of 31 male seniors ($n_{WB, Males} = 31$) and 10 female seniors ($n_{WB, Females} = 10$).

The freshman (FA) male and female participants ranged from 18 to 23 and 18 to 19, respectively. Within the creativity course senior participants (CA/CB), male ages ranged from 19 to 43, while female ages ranged from 19 to 41. Within the creativity workshop senior participants (WA/WB), male ages ranged from 21 to 35, and female ages ranged from 21 to 28. This information is only available for those who provided it. Though the age and gender

information is assumed to be indicative of the overall population, not all participants provided all requested information.

A MANOVA analysis was performed on all groups studied in order to determine the effects of age and gender on TCT-DP scores. Each group was evaluated individually based on averaged TCT-DP scores. No statistically significant correlations were found between age, gender or category and TCT-DP combined score for any of the study groups (FA, CA, CB, WA, and WB) except one. There was a significant correlation between the interaction of category and age with the TCT-DP score ($F = 1.857$, $P\text{-Value} = 0.021$). This may be due to the relatively narrow age range of some categories, versus other categories with larger age ranges available.

Another portion of the study testing was focused on critical thinking assessment through the WGCTA. This test was taken by a subset of those who volunteered for the TCT-DP testing. Ninety-five senior participants of the 112 senior participants who completed the TCT-DP opted to take WGCTA ($N_{CA, WGCTA} = 95$). Of the 95, only 86 completed the test ($n_{CA, WGCTA} = 86$). As such, the nine incomplete senior participant WGCTA tests were removed from the analysis due to skewing concerns. All 62 freshmen participants who completed the TCT-DP opted to take the WGCTA ($N_{FA, WGCTA} = 62$). Of the 62, only 59 completed the test ($n_{FA, WGCTA} = 59$). The three incomplete tests were removed from the analysis as well, due to skewing concerns.

A MANOVA was performed on the senior participant WGCTA data (CA, CB, WA and WB). The results provided no significant evidence that age ($F = 1.522$, $P\text{-Value} = 0.099$), gender ($F = 0.84$, $P\text{-Value} = 0.772$) or grouping variable ($F = 0.307$, $P\text{-Value} = 0.581$) had an effect on critical thinking scores. Due to the limited range of ages in the incoming freshman participants (WA), no significant effects were expected in terms of age for that group. Based on the analyses of the demographic data, the data represented an adequate sample in terms of gender and age.

Experiment 1 Results

Overview

Experiment 1 sought to understand the incoming creative and critical thinking abilities of freshmen and determine how they might be affected by the engineering curriculum over time, through comparison to the scores of the current senior group. Specifically, the research question asked if freshman engineers had higher creativity but lower critical thinking skills than the senior students. To do this, the data collected from the various study groups was statistically tested to determine if measurable, significant differences were present between the samples.

During the analysis of this data, some unexpected score differences were found between the senior pre-training samples (CA and WA) that, under the hypothesis and experimental design assumptions, should have been identical if not very similar. Due to the observed scoring differences, an in-depth statistical analysis was performed to determine the significance, impact and reasoning behind the anomaly, in order to determine which group's scores should be utilized as the senior group to best compare to the freshman in Experiment 1.

Understanding the Sample

When the experimental data was evaluated for statistical analysis, an unexpected difference was found between samples that were expected to be very similar, specifically the pre-training scores of the creativity course senior participants (CA) and the workshop senior participants (WA). Figure 12 depicts the boxplot of averaged data for the CA and WA groups. There were apparent differences between the means and overall values of the samples that were largely unexpected.

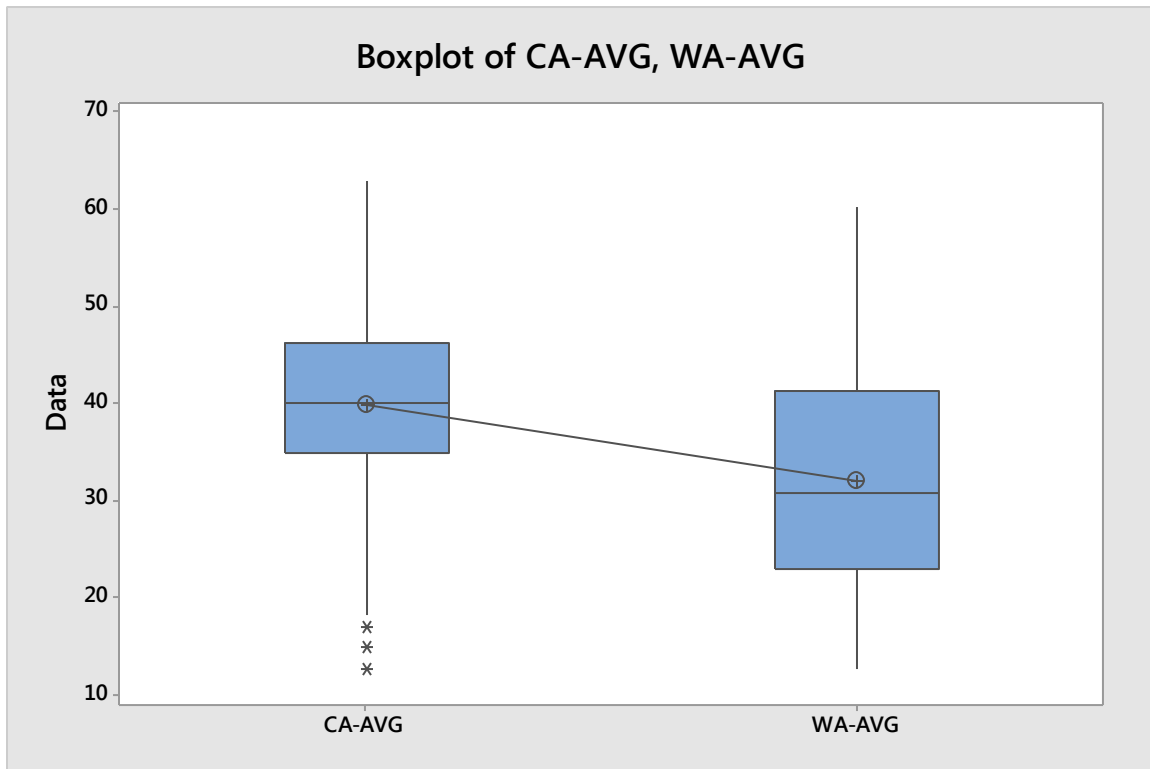


Figure 12: Plots of Averaged Data for Pre-Training Creativity Course (CA) and Workshop (WA) Senior Study Participants

Based on this discrepancy, an analysis was performed to determine if the differences between the pre-training creativity course seniors (CA) and creativity workshop seniors (WA) were significant. The statistical test provided strong evidence, with agreement from all raters' scores, that the two groups were in fact different ($F= 21.736$, $P\text{-Value} = 0.000$). Specifically, the pre-training creativity course seniors (CA) had significantly higher TCT-DP scores than the pre-training creativity workshop seniors (WA).

The two senior groups (CA and WA) were initially assumed to be equivalent in terms of incoming creative abilities, since both groups had been exposed to the same education and general environment. Considering that these two groups should have been similar to each other, the differences must have been caused by outside factors. As stated in Chapter 3, the creativity

course seniors were administered the pre-training creativity test six weeks after the course began, due to a delay in testing materials. Though no specific creativity training was given during this time, the course was taught by the same professor who also taught the later creativity portion. The students were also made aware of future creativity content, as well as the creativity testing. This appears to have had a large influence on their pre-training TCT-DP scores (CA). Rietzchel et al. provided strong evidence suggesting that, when merely asked to be creative, participants provided more creative products, though they themselves did not feel it was creative (2014). The expectation and anticipation of creative production is postulated as the reason for the majority of the difference in the scores between the pre-training creativity workshop seniors (WA) and pre-training creativity course seniors (CA), which should not otherwise have been significantly different.

Other studies also point to mere creative expectation as a means of creativity improvement. Scott and Bruce (1994) found that leadership, support for innovation and managerial role expectations were significantly related to innovative performance. Tierney and Farmer (2004) found that the supervisor's creative expectation was linked to a series of intermediate steps in the innovation process, which may lead individuals towards creative productivity. Other studies also point to creative expectation and expected evaluation as being tied directly to higher creative production (Shalley, 1995). These studies suggest that the level of creative expectation, and the environment in which these expectations are implied, has much to do with the creative production of participants.

Individuals develop their own expectations and acceptable behaviors based on the overall environment or climate of the workspace or educational setting (James, Hartman, Stebbins, & Jones, 1977). Based on these studies and their results, permission to be creative may be one true

reason for the marked increase in creativity. MailChimp CEO Ben Chestnut agrees that creative culture is essential for the success of creative production, including giving “yourself and your team permission to be creative” (Chima, 2011). This creative permission is not only permission to try new things, but permission to fail and have creative ideas. There is strong evidence in research and industry that this permission through both culture and environment is very supportive of innovation (Kelley, Littman, & Peters, 2001; Starko, 2014; Twohill, 2012). By informing students of future creativity testing and creativity training, the professor implicitly gave students permission to be creative in the case of the pre-training creativity course senior group (CA).

Another potential source of inadvertent training could have been the exposure of a percentage of the pre-training creativity course senior sample group to one semester of senior design. This capstone course places students in a “real world” project, which they follow from inception to implementation. Though project-based curricula make up a large portion of creativity training in engineering academia, there is also strong evidence that the students themselves do not find the curriculum they undertake to incorporate creativity (Kazerounian & Foley, 2007). As such, the true impact of a senior design capstone course is difficult to quantify. Inadvertent training through creative expectation and project-based engineering affected the creativity scores significantly, enough that the creativity course itself had a more muted impact on the senior creativity course group’s scores (i.e. comparisons of pre-training test CA vs. post-training test CB).

Given these significant differences between the pre-training scores of the course (CA) and workshop (WA) senior groups, comparative analyses were performed in order to determine which of the creativity sub scores were most influenced by the inadvertent creativity training the

CA group encountered. Significant differences were found within many of the sub scores of the TCT-DP between the CA and WA student groups. Specifically, there was strong evidence that pre-training creativity course seniors (CA) had higher scores than the workshop seniors (WA) in Cm, Ne, Cl, Cth, Bfi, Pe, Hu and Ucd. These attributes, per Table 3, are directly related to increased performance in flexibility, elaboration, composition, originality and risk-taking. The pre-training creativity course seniors (CA) entered the creativity testing significantly ahead of the pre-training creativity workshop seniors (WA). Table 6 details the results of the analyses performed.

Table 6
Comparative Analyses of TCT-DP Sub Scores between CA and WA Participant Groups

TCT-DP Sub Score	CA			WA			Hypothesis Testing	
	n	Mean	Std. Dev.	n	Mean	Std. Dev.	F	P
Cn	112	5.403	0.509	68	5.261	0.458	3.711	0.056
Cm	112	5.473	0.525	68	5.177	0.611	12.199	0.001
Ne	112	5.205	1.291	68	4.353	1.634	14.752	0.000
Cl	112	5.126	1.334	68	4.299	1.527	14.258	0.000
Cth	112	5.119	1.537	68	3.677	2.321	25.460	0.000
Bfd	112	1.211	2.305	68	0.770	1.900	1.842	0.176
Bfi	112	1.625	2.325	68	0.681	1.707	8.649	0.004
Pe	112	3.524	1.965	68	2.240	2.060	17.390	0.000
Hu	112	2.280	1.812	68	1.583	1.974	5.830	0.017
Uca	112	0.250	0.788	68	0.162	0.507	0.709	0.401
Ucb	112	1.107	0.981	68	1.093	0.910	0.010	0.919
Ucc	112	1.533	0.960	68	1.270	1.070	2.999	0.085
Ucd	112	2.051	0.868	68	1.593	0.969	10.687	0.001

The results of the analysis showed significantly higher TCT-DP scores across the majority of sub scores for the inadvertently trained pre-course seniors (CA) over the pre-workshop seniors (WA). The difference of over seven points in the scores is so large that it must have been due to external factors. This is posited to be due to creative expectation and, to some

extent, previous exposure to project-based instruction; both are established methods of creative improvement (Rietzchel, Nijstad, & Stroebe, 2014; Zhou, 2012; Blicblau & Steiner, 1998; Court, 1998; Scott & Bruce, 1994). Based on these results, the pre-training workshop seniors (WA) were designated as the most unadulterated sample for the "incoming" senior condition for Experiment 1, in order to most accurately compare untrained freshman engineering students (FA) to untrained senior engineering students.

Freshman and Senior Creativity Results

Based on a review of current creativity literature, senior engineering participants were expected to have lower levels of creative ability than the freshman engineering participants. With this hypothesis in mind, a MANOVA statistical analysis was performed on the incoming freshman data (FA) and the senior data (WA). As mentioned in the previous section, unforeseen factors prevented the pre-training creativity course senior participant sample group (CA) from being considered as the unaltered senior engineering student condition to compare against the freshman student group (FA). As such, the pre-training workshop creativity group (WA) was used as the comparative senior condition for the testing of Experiment 1's hypothesis. However, the freshman scores (FA) were also subsequently compared to the pre-training creativity course senior participants' scores (CA) to understand the depth to which creative expectation and project-based course work affected the CA group's creativity levels.

First, a MANOVA statistical analysis was conducted between the senior participant data (WA) and the incoming freshman participant data (FA). All MANOVA tests were conducted with a significance of $\alpha = 0.05$. All results included the hypothesis being performed and the related means, standard deviations and P-Values of the data.

There was not sufficient statistical evidence that the freshman group (FA) had higher scores than the senior group (WA) within the defined significance level ($F = 3.159$, $P\text{-Value} = 0.078$). However, there was significant evidence within the $\alpha = 0.10$ level. This suggests that enough evidence existed that the freshman scores (FA) were indeed measurably higher than those of the creativity workshop seniors (WA). These results expose a decline in creativity between the freshman and senior years of engineering students. This may have been due to three possible scenarios: the engineering curriculum had adverse effects, freshman students with creative skills moved away from engineering, or a combination of both. All scenarios are detrimental to the engineering profession, and action must be taken in order to address each of them. Evidence has shown a definite lack of creativity training within the engineering curriculum, and there is also extensive evidence of attrition from engineering majors (Kazerounian & Foley, 2007; Daempfle, 2003; Astin & Astin, 1992; Marra, Rodgers, Shen, & Bogue, 2012; Shuman, Delaney, Wolfe, Scalise, & Besterfield-Sacre, 1999).

A survey conducted by Kazerounian and Foley (2007) demonstrated strong evidence that engineering students are of the opinion that creativity is not addressed in any way through the engineering curricula. The results of this study support the opinions of the engineering students. Though other factors exist, the statistical results suggest that engineering education must address the creativity decline. Through the conclusions extracted from the statistical averages, graduates are becoming less creative in an economy driven by constant innovation (Hamel, 2002).

Comparative analyses were performed to determine which creativity sub score characteristics influenced overall test scores the most between the freshman group (FA) and the pre-training senior group (WA). There was strong evidence that freshmen earned significantly higher scores in Ne, Cl, Cth, Pe and Ucd. Senior engineering students' scores demonstrated

lower levels of divergent thinking (Ne) and synthesis thinking (Cl and Cth) skills, as well as some impact on their ability to produce novel solutions to problems (Ucd) as compared to the freshman group. This is detrimental in terms of overall creativity, and directly impacts the seniors' abilities to produce original solutions to the problems they face. This may be due to several factors, including the methodologies used in traditional engineering education. Table 7 details the comparative analyses performed.

Table 7
Comparative Analyses of TCT-DP Sub Scores between FA and WA Participant Groups

TCT-DP Sub Score	FA			WA			Hypothesis Testing	
	n	Mean	Std. Dev.	n	Mean	Std. Dev.	F	P
Cn	62	5.237	0.612	68	5.261	0.458	0.062	0.804
Cm	62	5.328	0.676	68	5.177	0.611	1.796	0.183
Ne	62	5.000	1.425	68	4.353	1.634	5.733	0.018
Cl	62	5.248	1.012	68	4.299	1.527	17.085	0.000
Cth	62	4.715	1.733	68	3.677	2.321	8.230	0.005
Bfd	62	0.387	1.486	68	0.770	1.900	1.613	0.206
Bfi	62	0.296	1.101	68	0.681	1.707	2.294	0.132
Pe	62	3.290	2.168	68	2.240	2.060	8.019	0.005
Hu	62	1.420	1.624	68	1.583	1.974	0.264	0.608
Uca	62	0.226	0.688	68	0.162	0.507	0.370	0.544
Ucb	62	0.935	0.807	68	1.093	0.910	1.082	0.300
Ucc	62	1.382	0.729	68	1.270	1.070	0.482	0.489
Ucd	62	1.930	0.930	68	1.593	0.969	4.072	0.046

There was a significant reduction in creativity scores between freshman participants (FA) and the pre-training workshop seniors (WA). The results of this experiment directly support this conclusion. It is clear that a problem existed that affected the engineers over the duration of their engineering education. Based on the surveys conducted by Kazerounian and Foley (2007) and other studies, this may have been directly attributable to the lack of focus on creativity in the

engineering curriculum. This problem must be addressed expediently, as the current system is hindering the students' creative progress.

The inadvertent training of the pre-training creativity course seniors (CA) provided an opportunity to understand how even some limited creativity training changes this scenario. To understand how the freshmen (FA) compared to the pre-training creativity course seniors (CA), a statistical analysis was conducted. Based on the boxplots of the two groups (Figure 13), as well as a comparison of their means, the hypothesis testing was modified to determine if the pre-training creativity course seniors (CA) who received some inadvertent training had statistically higher scores than the freshmen (FA).

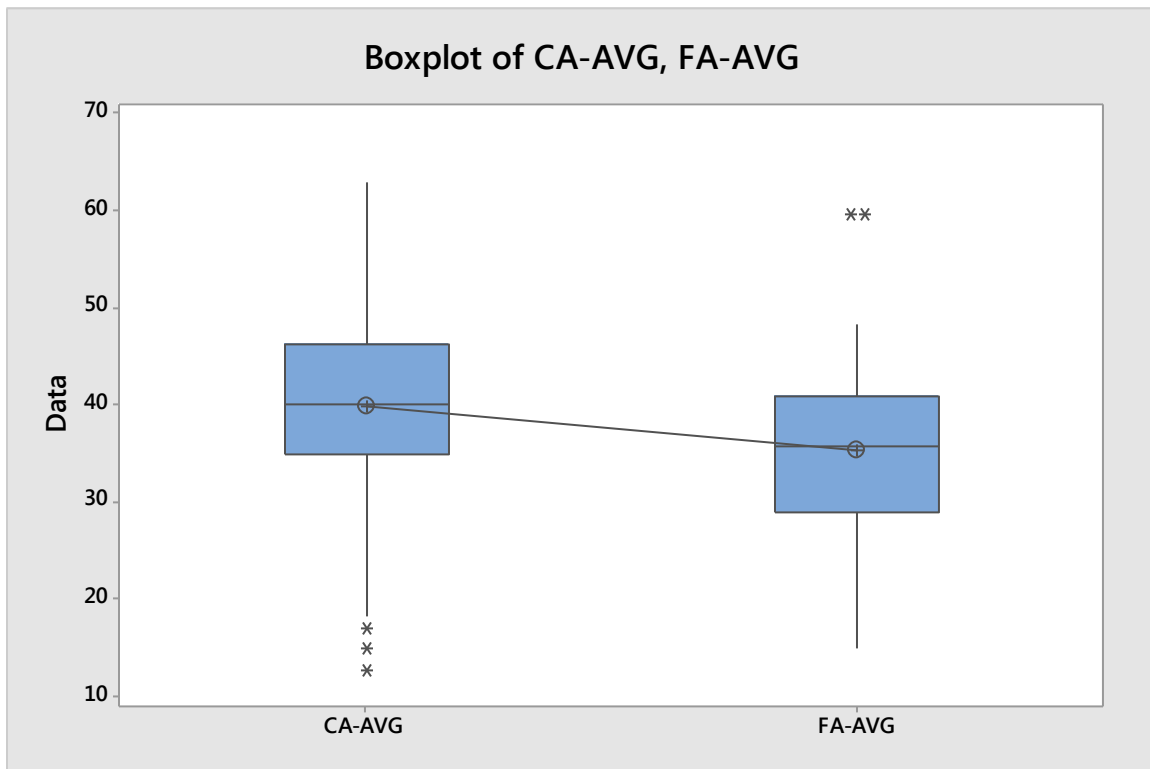


Figure 13: Plots of Averaged Data for Pre-Training Creativity Course Senior (CA) and Freshman (FA) Study Participants

A MANOVA analysis was conducted on the TCT-DP scores between pre-training creativity training senior (CA) and freshman (FA) engineering students. Based on senior and freshman TCT-DP scores, significant evidence was found that the senior pre-training course participants (CA) had higher creativity scores than freshman participants (FA). This is in stark contrast to the statistical results of the pre-training workshop seniors (WA) and the freshmen (FA) ($F = 8.299$, $P\text{-Value} = 0.004$). Creativity training, even when done inadvertently in the case of the CA group, can have a significant impact on students' creative skills. On average, the scores improved by more than four points.

These large increases in creative skill support the workplace talents necessary for engineers to produce more innovative, ground-breaking products. Engineers today must be capable of not only making calculations, but also of understanding the problems they are given and solving them in unique ways. Without this capability, their skill set is weakened and leaves them vulnerable to other engineers who may already be more naturally inclined toward creativity. To better understand which creativity sub scores were directly affected, comparative analyses were performed on the freshman (FA) and pre-training creativity course senior (CA) data sets. Table 8 details the results of the comparative analysis performed in order to determine the sub scores that significantly impacted the seniors' overall creativity scores.

The comparative analysis shows a statistically significant difference between seniors and freshmen for sub scores Bfd, Bfi and Hu. These attributes are linked to the improvements in risk-taking and emotional transference often associated with creative individuals. The inadvertent training (i.e. creative permission and expectation) provided the CA senior group with the kinds of tools necessary to take risks and solve problems more effectively, and take not only their own emotions, but also the emotions of others into consideration in their designs.

Table 8

Comparative Analyses of TCT-DP Sub Scores between FA and CA Participant Groups

TCT-DP Sub Score	CA			FA			Hypothesis Testing	
	n	Mean	Std. Dev.	n	Mean	Std. Dev.	F	P
Cn	112	5.402	0.508	62	5.237	0.612	3.779	0.054
Cm	112	5.473	0.525	62	5.328	0.676	2.613	0.108
Ne	112	5.205	1.291	62	5.000	1.425	0.893	0.346
Cl	112	5.125	1.334	62	5.248	1.012	0.422	0.517
Cth	112	5.119	1.537	62	4.715	1.733	2.665	0.104
Bfd	112	1.211	2.305	62	0.387	1.486	6.563	0.011
Bfi	112	1.625	2.325	62	0.296	1.101	18.305	0.000
Pe	112	3.524	1.965	62	3.290	2.168	0.539	0.464
Hu	112	2.280	1.812	62	1.420	1.624	9.645	0.002
Uca	112	0.250	0.788	62	0.226	0.688	0.049	0.826
Ucb	112	1.107	0.981	62	0.935	0.807	1.383	0.241
Ucc	112	1.533	0.960	62	1.382	0.729	1.223	0.270
Ucd	112	2.051	0.868	62	1.930	0.930	0.733	0.393

It is clear that the inadvertently trained pre-course senior engineers (CA) scored as being significantly more creative than the freshman engineers (FA). Based on the findings between the creativity course seniors (CA) and the freshmen (FA), creativity course seniors had higher performance in their creativity scores based on improvements in emotional sensitivity and divergent thinking (detectability), per Table 3.

These analyses show strong statistical evidence that creativity has been negatively impacted through the progression of the college engineering coursework, but even small steps in creativity training (i.e. the creative expectation on the CA group) can provide significant improvements in creative ability. As mentioned previously, this may have been due to three possible scenarios: the engineering curriculum had adverse effects, freshman students with creative skills moved away from engineering, or a combination of both. All scenarios are

detrimental to the engineering profession, and action must be taken in order to address each of them. The current coursework may be negatively affecting students' skills necessary for long-term growth within their field. If not due directly to the coursework, the style of traditional instruction in the engineering field may be driving creative freshmen from the major. Without definitive changes, the creativity decline will continue due to loss of creative talent and lack of creativity instruction. This lack of creativity in engineering leads to less innovative engineers, with reduced professional viability in a changing world.

Freshman and Senior Critical Thinking Results

The second hypothesis explored in Experiment 1 tested whether senior engineering students have better critical thinking skills than those of the incoming freshman engineers. It is a long-held belief in society that engineers are critical thinkers due to the focus of their degree and their problem solving skills. Based on the original construct of the study, the pre-training creativity course senior group's (CA) TCT-DP and WGCTA scores were to be compared to the incoming freshman (FA) TCT-DP and WGCTA scores. Due to the inadvertent creativity training the creativity course seniors (CA) experienced before the actual creativity portion of their course (i.e. the setting forth of the expectation that they would need to think creatively in order to fulfill the course requirements), the TCT-DP scores of the freshmen (FA) were compared against the pre-training creativity workshop seniors' (WA) scores, as these were used as the baseline senior scores instead. However, in the case of critical thinking skills, it was postulated that neither senior group was exposed to additional critical thinking training beyond the undergraduate coursework, and therefore the critical thinking performances of the pre-training creativity course seniors (CA) and creativity workshop seniors (WA) were considered equivalent.

To test the second hypothesis of Experiment 1, the WGCTA scores of the pre-training creativity course seniors (CA) were compared to the incoming freshman (FA) WGCTA scores using a MANOVA test. For this analysis, WGCTA tests that were not complete (i.e. test that were missing answers for entire sections) were removed from the analysis due to the possibility of skewing of scores. Of the freshman WGCTA tests submitted, three tests were not complete. Of the senior WGCTA tests submitted, nine tests were not complete. The results did not provide enough evidence to reject the hypothesis. There was no statistically significant difference between the two samples, suggesting that there was no significant critical thinking change between incoming freshman students and seniors nearing completion of their engineering coursework ($F = 1.054$, $P\text{-Value} = 0.306$).

Based on the statistical performance, it appears the engineering students are not learning to think more critically throughout their coursework. This implied that senior engineering students were no more able to define and evaluate problems than their freshman counterparts. Not only did the cumulative scores show that the freshmen and seniors had similar critical thinking skills, the means and boxplots (Figure 14) of the data suggested that freshmen may actually outperform seniors in some sub categories. As such, a comparative analysis was conducted to determine if any of the WGCTA sub scores demonstrated a significant difference between the two sample groups.

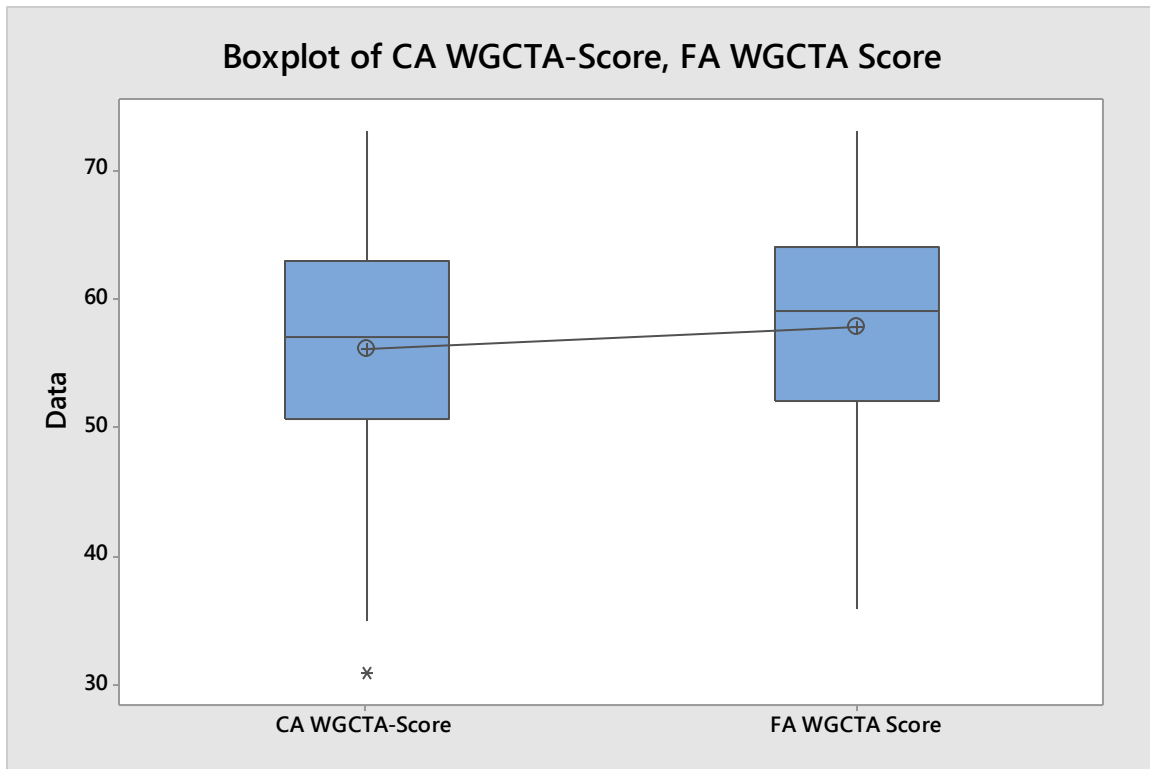


Figure 14: Boxplots of Pre-Training Creativity Course Senior (CA) and Incoming Freshman (FA) WGCTA Scores

The comparative analyses showed two sub scores where freshman participants performed better than senior participants. A statistically significant difference was found for the evaluation of arguments ($F = 5.084$, $P\text{-Value} = 0.026$). Table 9 shows the detailed results for the WGCTA sub scores. Evidence also exists within $\alpha = 0.10$ that suggested freshman engineering students out-performed senior engineering students in inference as well. Based on the test descriptions provided within the manual, this suggests that the freshmen were better able to discriminate "among digress of truth or falsity of inferences drawn from data", as well as distinguish "between arguments that are strong and relevant" (Watson & Glaser, 2008).

Table 9

Comparative Analyses of WGCTA Sub Scores between CA and FA Participant Groups

WGCTA	CA			FA			Hypothesis Testing	
	n	Mean	Std. Dev.	n	Mean	Std. Dev.	F	Sig.
Inference	86	8.686	2.503	59	9.441	2.402	3.287	0.072
Recognition Of Assumptions	86	11.593	3.765	59	11.678	3.345	0.019	0.889
Deduction	86	11.965	2.659	59	11.627	2.606	0.575	0.450
Interpretation	86	12.116	2.513	59	12.322	2.403	0.243	0.623
Evaluation of Arguments	86	11.802	2.524	59	12.695	2.045	5.084	0.026

Based on these results, the freshmen were more capable of understanding and analyzing problems than the seniors. This is significant, as their engineering education actually seems to have had a negative effect on portions of the seniors' critical thinking skills. Both creativity and critical thinking were either negatively impacted by the education that was thought to support them, or those students capable of high-level creative and critical thinking moved to other majors. Serious changes must be considered and implemented in order to produce better engineers. Innovation is a combination of critical thinking and creativity. The study results suggested that these skills were degraded by the very education intended to improve them.

Based on the normality concerns addressed earlier for the pre-training creativity course seniors' (CA) WGCTA data, a non-parametric analysis was conducted in order to ensure the results of the parametric analysis were accurate. A Mann-Whitney U Test suggested that there was no significant difference between the WGCTA scores of the study freshmen (FA) and the pre-training creative course seniors (CA) ($U = 2360.50$, $P\text{-Value} = 0.477$). These results agreed with the results of the parametric analysis.

The WGCTA manual provided normative data for the groups being tested through this study. To better understand how the engineers in the study group compared to the general population, statistical tests were conducted against the related norms. This allowed for the

comparison of the “expected” averages of the various groups (i.e. incoming freshman and upper division students in four-year colleges) against the actual data collected for both the engineering freshmen and senior participants in this study (Watson & Glaser, 2008). Comparing the FA and CA groups’ data to the normative data provided in the WGCTA manual, there was a statistically significant difference between both groups and their respective norms. The results of the statistical analyses are detailed in Table 10.

Table 10
T-Test Results for Freshman (FA) and Creativity Course Senior (CA) WGCTA Scores against Respective Norms

Study Samples vs. WGCTA Norms								
FA			Freshman Norms			Statistical Info		
n	Mean	Std. Dev.	n	Mean	Std. Dev.	T-Test	T-Value	P-Value
59	57.76	8.33	824	53.8	9.2	0 vs. ≠	3.5	0.001
						0 vs. >		0.000
CA			Upper Division Norms			Statistical Info		
n	Mean	Std. Dev.	n	Mean	Std. Dev.	T-Test	T-Value	P-Value
86	56.16	9.78	417	59.2	8.4	0 vs. ≠	-2.69	0.008
						0 vs. <		0.004

The incoming freshman engineers (FA) scored significantly higher than the average for their normative group. This is an understandable difference, as the norm takes the entire student population into account. Those wishing to be engineers are presumed to have some innate problem solving capabilities that would allow their average to be above the general average. The study freshman group’s (FA) average is at the 70th percentile (freshman average) when compared to the normative average (50th percentile). The senior participants (CA), on the other hand, scored significantly lower than their corresponding normative group, moving from the 50th percentile (norm average) to slightly above the 35th percentile (senior average). Figure 15 depicts these results in a graph showing the extent to which the engineering freshmen came in above

their peer normative averages, and the seniors came in below their peer normative averages, respectively.

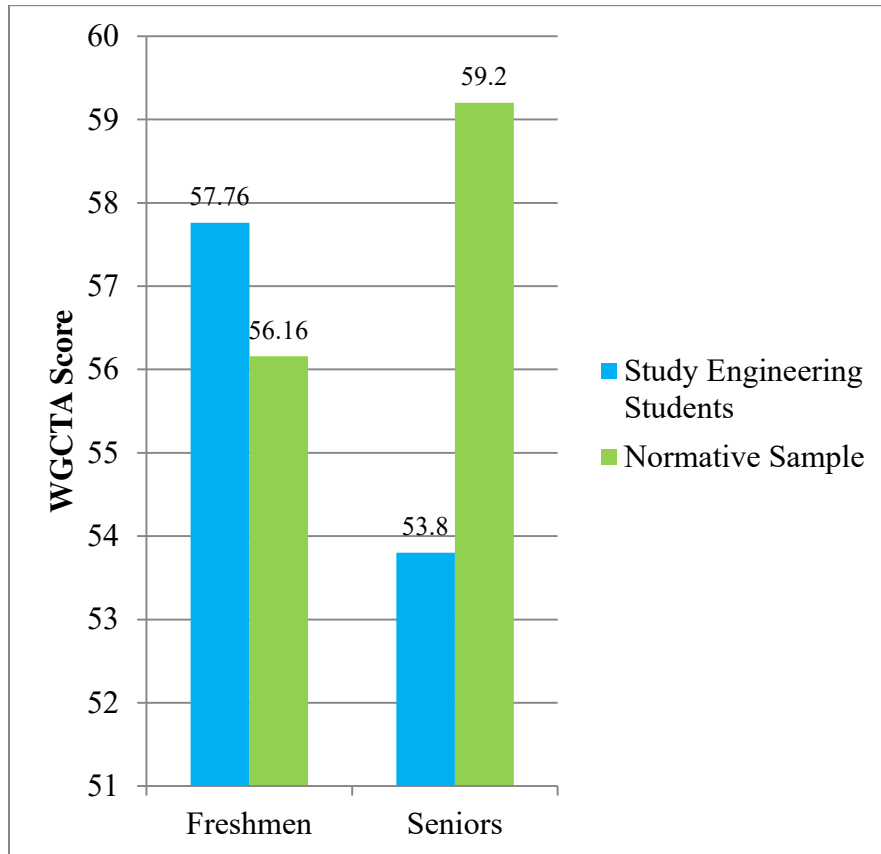


Figure 15: WGCTA Study Scores versus Normative Data

Based on this evidence, engineering education is having adverse effects on the critical thinking capabilities of engineers. This could be attributed to the standard practice of book-based learning, which focuses on solving single-solution problems and general over-constraint due to the risks of engineering design (Kazerounian & Foley, 2007). This process does not allow for general problem solving/critical thinking development, as the normative analysis strongly suggests. As such, the open-format writing, discussion and engagement techniques used in the educational methodology of many other types of college majors may actually be supporting

those students' critical thinking skills better than the engineering curriculum is supporting those of the engineers.

Experiment 1 Summary

Experiment 1 determined the overall incoming condition of freshman and senior engineers to determine what effects the engineering education curriculum had on the creative and critical thinking abilities of the engineering students. The results found were significant in terms of the effects of engineering education.

The statistical analysis of the TCT-DP results found that freshman engineers (FA) performed more creatively than senior engineering students (WA). Though general life events and aging may have something to do with this change, the only known shared experience between all of the study's pre-training creativity workshop seniors (WA) was their progression through the same engineering curriculum. The loss of creative ability is a serious concern in engineering. Creative problem solving is the foundation of the engineering profession, necessary in order to resolve the design-based issues facing the world. When this is taken into account, the findings discussed here are all the more important to consider.

The results of the WGCTA statistical testing led to similarly interesting results. Since critical thinking is an essential skill in problem solving, it is assumed that the engineering curriculum develops and strengthens this skill throughout the students' academic careers. Studies in the critical thinking literature, as well as the WGCTA norms, support this increase in critical thinking skill as result of exposure to both college life and college education (Watson & Glaser, 2008; Pascarella, 1987; Keeley S. M., 1992; Spaulding & Kleiner, 1992; Mines, King, Hood, & Wood, 1990). The results of this study demonstrated that critical thinking skills are actually

stagnant in engineering students. The stagnation is such that senior engineering students are not performing at the average level of the general population of their associated group. This was supported by the comparative analyses, which revealed the freshmen had better critical thinking capabilities than seniors in the areas of inference and the evaluation of arguments.

Based on these negative findings regarding the comparatively lower critical thinking abilities of the senior engineering students versus the freshman engineers, the study groups' data was then compared to their respective normative data groups. This analysis was conducted in order to determine how the study's groups compared to the general population of students in their same grade levels. The freshman engineers (FA) were compared against the norms representing the general freshman population provided by the WGCTA manual. The senior engineers (WA) were compared against the norms representing the general upper division population for four-year colleges.

The incoming freshmen scored significantly higher than the average students within their normative group. The freshman engineers (FA) placed significantly higher than their respective normative group while the senior engineering students placed significantly lower than their respective normative group. Based on this evidence, either their engineering education, or the attrition of critical thinkers from the engineering program, resulted in significant adverse effects on the overall critical thinking capabilities of senior engineering students. The book-based learning approach prevalent in engineering education may be stagnating critical thinking development by providing direct problems that do not need further understanding to solve. This approach hampers the ability for general problem solving and critical thinking development. As such, the open format writing, discussion and engagement of many other college major programs

may actually be supporting those students' critical thinking skills better than the engineering program.

The study suggested that freshman engineering students are more creative than senior engineering students. Critical thinking scores were also demonstrated to be stagnant between the two groups, and degraded when compared to normative data. As mentioned earlier, this may be due to three scenarios: the engineering curriculum had adverse effects, freshman students with high critical thinking and creative skills moved away from engineering, or a combination of the two. Both scenarios are detrimental to the engineering profession, and action must be taken in order to address each of them. The factors driving away potentially exceptional students must be understood and corrected in order to better retain the potential talent the engineering field may be losing. Additionally, the factors within the engineering curriculum negatively impacting the critical thinking and creativity of engineers must also be discovered and addressed. As such, a longitudinal study must be conducted to understand the true source of the creative decline and critical thinking stagnation within engineering.

This experiment has further confirmed several findings in current literature, but has also furthered our understanding of critical thinking in engineering students. The creativity decline is apparent in engineering undergraduates. Also, the experiment further confirmed the critical thinking stagnation findings of Douglas (2012), and Ozyurt and Ozyurt (2015), but additional insight was evident when comparing the study data to normative data. Critical thinking is actually significantly lower in engineering senior students as compared to students in other majors. This finding is significant, as the problem solving capabilities of engineering students are reduced compared to other fields of study. The experiment's results suggested that an in-depth look at engineering curricula is needed to better address the concerns brought here to light.

Engineering curriculum needs to be examined holistically in order to determine the deficiencies that are driving the declines seen in these results. A longer discussion can be found in Chapter 5.

Experiment 2 Results

Overview

Experiment 2 sought to determine how varying durations of creativity training affected the creative skills of undergraduate college students. The research question asked if long-term creativity training (six weeks) affected creative skills in students to a larger extent than short-term creativity training (one to two hours). To do this, the data collected from the various study groups was statistically tested to determine if significant changes were evident between the samples.

Existing studies point toward short-term creativity training as providing measurable changes to creative skills (Genco, Johnson, Holtta-Otto, & Conner Seepersad, 2011; Clapham M. M., 1997). This study aimed to determine if, in fact, short-term training does have an effect, and if the effect is as significant as longer-term training. The additional aspects and subject depth that can be incorporated into longer-term creativity training would suggest additional benefits for the participants' creative skills. Within this section, the short-term creativity training group was the creativity workshop seniors (WA and WB). The long-term creativity training group was the creativity course seniors (CA and CB).

Statistical Considerations for Paired Samples

Since the following experiment is based on pre- and post-testing of related groups (CA to CB, and WA to WB), some statistical considerations were taken into account in order to perform related sample statistical tests. The creativity course (CA to CB) and creativity workshop (WA to

WB) senior groups were found to have uneven samples for their respective pre-tests versus post-tests completed. As such, the samples were manipulated using the statistical software, and a random set of data points were removed from the pre-testing sample of both the creativity course (CA) and creativity workshop (WA) seniors, to accommodate for those who did not also complete the post-test. Again, the data removed was randomly selected by the statistical software random exclusion feature.

The creativity course pre-training group (CA) contained 112 participants, while the post-training group (CB) contained 105. In order to perform a related sample analysis, the pre-training sample was randomly culled of the data for 7 participants. The pre-training creativity course seniors (CA) had a sample size of 112, mean of 39.90 and a standard deviation of 10.46 before the random exclusion. After the exclusion of participant data, the sample size was 105, mean of 39.93 and a standard deviation of 10.66. A T-Test provided no evidence that the samples were statistically different (T-Value = -0.02, P-Value = 0.986).

The creativity workshop pre-training group (WA) contained 68 participants, while the post-training group contained 65. In order to perform a related sample analysis, the pre-training sample was randomly culled of the data for 3 participants. The pre-training creativity workshop seniors (WA) had a sample size of 68, mean of 32.16 and a standard deviation of 11.45 before the random exclusion. After the exclusion of participant data, the sample size was 65, mean of 32.62 and a standard deviation of 11.44. A T-Test provided no evidence that the samples were statistically different (T-Value = -0.23, P-Value = 0.816).

The statistical evidence showed no evidence that the randomly removed data points significantly changed the descriptive statistics of the data. As such, the following sections will use the culled data sets (for CA and WA) in the various analyses performed.

Creativity Workshop Results

Students in a creativity workshop were asked to participate in this study before and after completing their creativity workshop training. Students were provided with the pre-training TCT-DP Form A testing materials before the multi-topic workshop began. The post-training materials (TCT-DP Form B) were provided directly after creativity training had finished. The results of the testing were evaluated and analyzed using repeated measures MANOVA in order to determine if the pre-training and post-training scores showed an improvement in creativity skills, as determined by the TCT-DP guidelines. Based on the analysis of the workshop participants, there was no evidence found of a significant difference between the pre- (WA) and post-testing (WB) scores ($F = 0.036$, $P\text{-Value} = 0.850$). This implies that short-term creativity training does not significantly impact creativity.

Though there was no evidence that the combined scores of the pre-training creativity workshop group (WA) were different from their post-training combined scores (WB), comparative analyses were performed on the pre-training and post-training creativity workshop data. These analyses provided a better understanding of how specific sub scores of the TCT-DP were affected by the short-term training. There no evidence suggesting any individual sub score was improved based on the short-term training. Table 11 details the analysis of the sub scores.

Table 11

Comparative Analysis of Pre-Training Creativity Workshop (WA) and Post-Training Creativity Workshop (WB) Seniors Using a Repeated Measures MANOVA

TCT-DP	WA			WB			Hypothesis Testing	
	Sub Score	n	Mean	Std. Dev.	n	Mean	Std. Dev.	F
Cn	65	5.273	0.465	65	5.032	0.876	3.771	0.057
Cm	65	5.206	0.580	65	4.851	1.345	3.554	0.064
Ne	65	4.426	1.613	65	4.323	1.702	0.126	0.724
Cl	65	4.323	1.558	65	4.529	1.497	0.550	0.461
Cth	65	3.703	2.339	65	3.528	2.202	0.170	0.681
Bfd	65	0.805	1.936	65	0.969	2.091	0.248	0.620
Bfi	65	0.697	1.742	65	1.292	2.190	2.704	0.105
Pe	65	2.318	2.067	65	1.811	1.785	2.313	0.133
Hu	65	1.656	1.990	65	1.436	1.818	0.378	0.541
Uca	65	0.169	0.517	65	0.354	0.856	2.542	0.116
Ucb	65	1.128	0.910	65	1.062	0.884	0.214	0.645
Ucc	65	1.292	1.073	65	1.318	0.997	0.020	0.887
Ucd	65	1.626	0.968	65	1.728	1.051	0.393	0.533

Creativity Course Results

The second part of the research questions from Experiment 2 dealt with the effects of long-term creativity training (CA and CB) on engineering students. This differs from the creativity workshop participants (WA and WB) in that the creativity training duration was six weeks, versus the workshop creativity training which consisted of only a limited session (one to two hours). To determine the extent to which the long-term creativity training was more effective than the shorter-term training, a repeated measures MANOVA statistical analysis was conducted. This analysis compared the data between the pre-training creativity test scores (CA) and the post-training creativity test scores (CB) for the senior group in the creativity course. Based on the comparison of tests between the creativity course pre-training (CA) and post-training (CB) conditions, this study's results found no significant change in creativity scores before and after

the course ($F = 0.190$, $P\text{-Value} = 0.664$). These results must be interpreted in combination with the earlier determination that the pre-training creativity course seniors had already been exposed to inadvertent creativity training before being tested in the “pre-training” condition (CA).

Due to the normality concerns addressed earlier in this chapter, the data was analyzed using non-parametric Wilcoxon Signed Ranks Test, due to the samples being related. The non-parametric tests were in agreement with the parametric results. The combined scores suggested that no significant change was found between the pre- (CA) and post-training (CB) conditions of the seniors who participated in the creativity course ($Z = -.303$, $P\text{-Value} = 0.762$).

Though the combined scores showed no evidence of significant improvement in TCT-DP scores, the data distribution appears to point to some interesting effects between the pre-training (CA) and post-training (CB) scores. The pre-training and post-training scores are tied directly to one course and one student population. Though not all students participated in both testing cycles, the majority of the testing was completed by the same participants (i.e. the same students participated in both the pre-training and post-training testing). As such, the results detail changes within the population whose only direct exposure to creativity training was presumed to be limited to this course, during the extent of the creativity training portion. Figure 16 shows many of the pre-training scores (CA) were very close to the mean. However, the post-training scores (CB) appeared to be driven toward the extremes. This suggests that some participants found benefit in the training, while others may have actually been negatively affected by the training. This is intriguing, as it suggests creativity training must be provided in a manner that engages many different types of students with different learning styles. One possible factor may be due to the time limitations placed upon the long-term creativity course, due to its incorporation into an existing course plan instead of being allotted a full-term class on its own. The original model

creativity course on which this training was designed includes additional exercises and immersion, which were removed from the instruction of the creativity course in an attempt to accommodate the time limitations of the semester. Understanding which aspects of the creativity course training were effective for some and which had detrimental effects could prove essential for the development of future creativity training curricula.

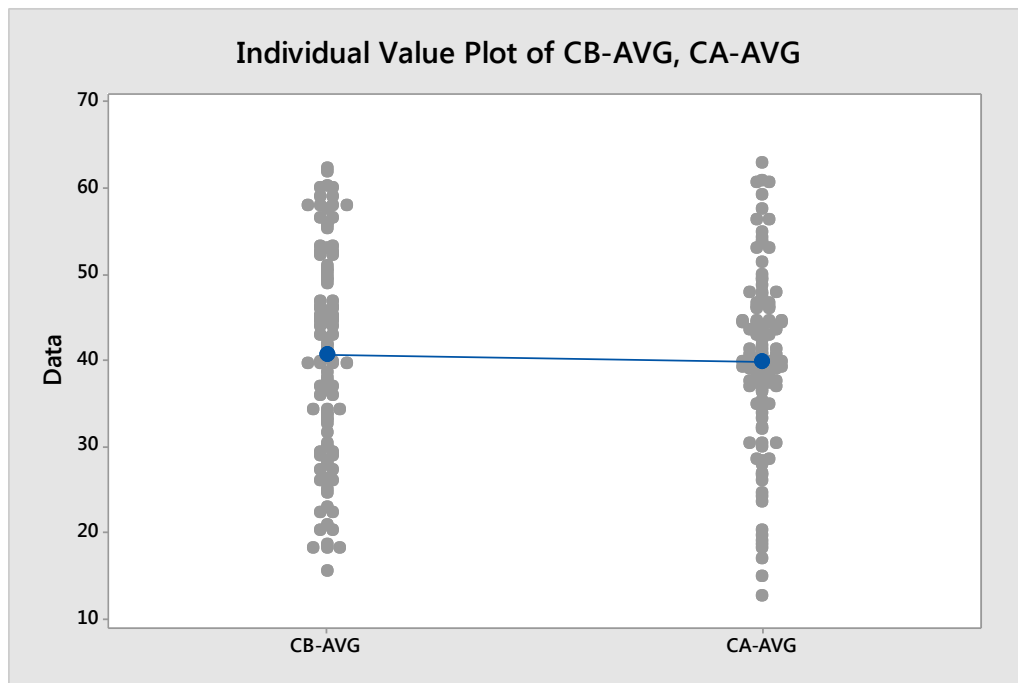


Figure 16: Individual Value Plot for Pre-Training Creativity Course Senior (CA) TCT-DP Averaged Scores vs. Post-Training Creativity Course Senior (CB) TCT-DP Averaged Scores

Though no significant changes were found in the combined score analysis, the changes seen in Figure 16 suggested that a comparative analysis of the sub scores of the test might point to sub scores that experienced significant change between the pre- (CA) and post-test (CB). Through the comparative analysis, several statistically significant differences were found. There was strong statistical evidence that exhibited improvements from the course for Bfd, Bfi and Uca. These characteristics are directly linked to improvements in curiosity/flexibility, detectability

and risk-taking, per Table 3. They are associated with an increased willingness to take risks and utilize divergent thinking processes. Table 12 details the results of the comparative analyses.

Table 12
Comparative Analysis of Pre-Training Creativity Course Seniors (CA) and Post-Training Creativity Course Seniors (CB) using a Paired T-Test Evaluation

TCT-DP Sub Score	CA			CB			Hypothesis Testing	
	n	Mean	Std. Dev.	n	Mean	Std. Dev.	F	P
Cn	105	5.404	0.517	105	5.439	0.578	0.174	0.677
Cm	105	5.473	0.533	105	5.429	0.696	0.235	0.629
Ne	105	5.162	1.321	105	5.041	1.240	0.444	0.507
Cl	105	5.096	1.365	105	4.933	1.246	0.715	0.400
Cth	105	5.127	1.494	105	4.178	2.007	13.308	0.000
Bfd	105	1.241	2.328	105	2.375	2.772	9.748	0.002
Bfi	105	1.682	2.341	105	2.705	2.566	7.707	0.007
Pe	105	3.505	1.994	105	2.701	2.004	8.081	0.005
Hu	105	2.279	1.822	105	2.105	2.003	0.458	0.500
Uca	105	0.267	0.812	105	0.705	1.117	10.593	0.002
Ucb	105	1.114	0.993	105	1.330	0.954	2.484	0.118
Ucc	105	1.521	0.974	105	1.556	1.034	0.063	0.802
Ucd	105	2.061	0.867	105	2.185	0.829	1.147	0.287

There was also strong evidence that sub scores Cth and Pe were higher in the pre-training scores (CA) than in the post-training scores (CB). This evidence points to a decline in synthesis and analysis capabilities, two important categories of convergent and divergent thinking. This may be due, in part, to the increased willingness for creative risk-taking behavior in the post-training CB scores as suggested by the comparative results. As a result of increased risk-taking, more novel drawings were incorporated into the drawing production in students' post-training tests without focused attention to synthesis, which resulted in some detrimental effects. These changes can impact the thematic quality of the drawings, such as drawing standard scenery or integrated compositions, by overriding the need for a theme with more abstract thoughts through

divergent thinking processes. Boundary breaking (Bfd and Bfi) appears to be related to expertise, as the senior students had improved scores in this category over the freshmen as well as additional creativity training from the course (CA vs. CB) in the post-test scores. This may have been due to increased expertise and confidence in the knowledge they possessed as they neared completion of their engineering courses.

The senior-level participants reacted well to creativity training in terms of the sub score Bfi. The creativity course seniors' results showed evidence of improving their Bfi sub scores with and without extended creativity training to support them. These results seem to imply that increased knowledge in a specific area, specifically engineering in the case of the participants, may actually have affected their creative risk-taking behavior. This implies senior engineering students are very open to training that supports creatively risky decisions. Interestingly, Cropley and Cropley (2000) also found evidence of significant improvements in Bfi as a result of training engineering students.

The results of this study suggested that engineers are relatively uncreative, as well as limited in their critical thinking skills. Data posted by the USTPO and analyzed by Dennis Crouch, Associate Professor at the University Of Missouri School Of Law, found that the majority of U.S. patents are in technology-based fields, presumably driven by novel inventions of engineers (Crouch, 2015). Though some of the patents are bound to be submitted by engineers on the high end of the creativity spectrum, a good percentage must be those closer to the average population. Additionally, gaining expertise in engineering was found to have a close relationship with the creativity present in the end products designed (Christiaans & Venselaar, 2005; Ericsson, 1999).

These study results appeared to be contradictory to the conclusions drawn from both the high throughput of intellectual property developed by engineers, and the positive results found through the gaining of engineering expertise. The Bfi scores provide the link between the deficits found in general creativity within the study, and the continued ability of some engineers to still develop creatively unique solutions to existing problems. With the ability to improve upon creative risk allowance as expertise is gained, engineers have been able to use this trait to keep up with the growing need for innovators in the engineering space. Further study into this relationship is needed to determine if this natural tendency to improve upon creative risk-taking can be further developed through focused training.

Additionally, the creativity training techniques used may have also had an effect as to how the students' creativity was impacted. The methodologies used within the creativity course focused on divergent ideation, which supported the improvements to some sub scores as seen in the study (CA vs. CB), but may have affected other sub scores negatively. By including additional techniques to address areas of synthesis and analysis, the training could lead to significant improvements above and beyond those already seen due to the inadvertent creativity training early on (CA), when the expectation was set for the course that it would require creativity of the students.

Further studies on training methods need to be conducted in order to determine the best approach to creativity training. With a test such as the TCT-DP, which explores various aspects of creativity, a more focused course may be developed to address the underlying characteristics or items that constitute the sub scores of the TCT-DP. Since senior students appear to be more willing to take risks as a result of their training, initial efforts may use this as a starting point for creativity training. A more intensive creativity course, such as the graduate Innovation in

Engineering Design course, would be a logical next step in terms of creativity training within the University of Central Florida Engineering Department.

Creativity Training Duration Comparison

Based on the sets of results from the creativity workshop seniors (WA and WB) and the creativity course seniors (CA and CB), it appears that long-term creativity training may be more effective at increasing creative skill. These results stand, even against the inadvertent prior training exposure experienced by the pre-training creativity course seniors (CA). With results suggesting improvements from long-term training, an analysis was conducted to statistically determine if the average differences of improvements between the pre- and post-training conditions were indeed better for the creativity course group (CA vs. CB) over the workshop group (WA vs. WB).

A repeated measures MANOVA was conducted to determine if long-term creativity (six weeks of a creativity training course, from CA to CB) provided a significant improvements over short-term creativity training (one to two hours of creativity training, from WA to WB). There was strong evidence that the long-term creativity training was significantly more effective at increasing creativity scores, as measured by the TCT-DP, than short-term creativity training ($F = 40.381$, $P\text{-Value} = 0.000$). Figure 17 depicts these results in a graph.

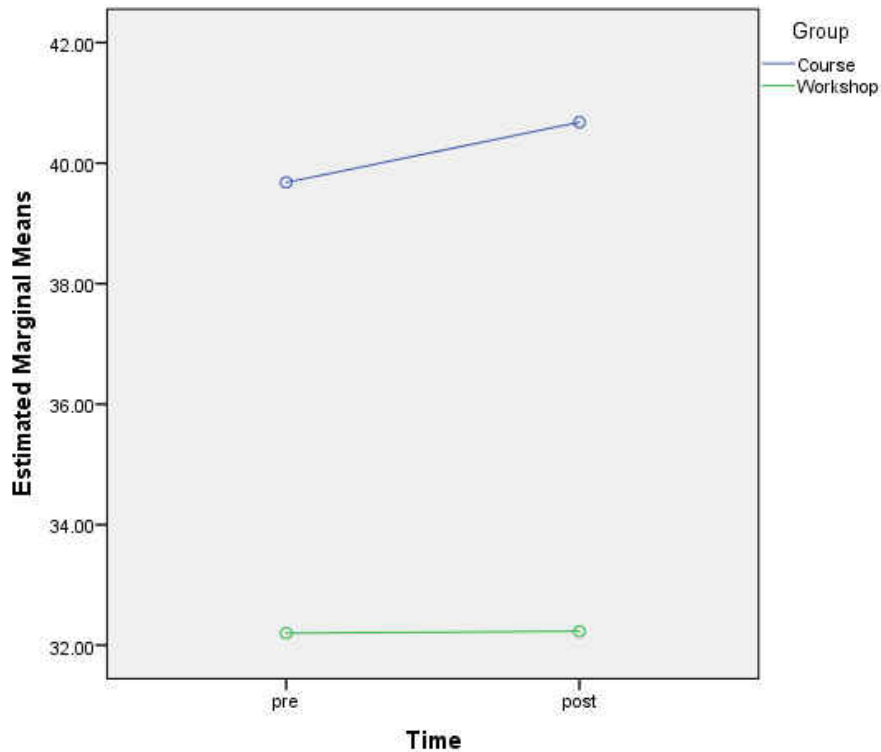


Figure 17: Graphical Results of Repeated Measures MANOVA for Short-Term Versus Long-Term Creativity Training

Long-term creativity training can provide significant improvements in creativity (CA vs. CB), even when the subjects have already received some amount of training beforehand. As such, these results suggest that continuous creativity training has additional benefits for the individuals being trained. The engineering curriculum must be updated to consider this finding as an indicator of the potential for continued improvement for student engineers. Not only can creativity training provide benefit once, but continued additional improvements are possible for creative abilities when longer exposure is provided.

Experiment 2 Summary

This experiment sought to determine if long-term creativity training (CA to CB) improved creativity more than short-term creativity training (WA to WB), as measured by the

TCT-DP. The analyses performed provided some suggestive results, which were not immediately apparent. These results suggested that long-term creativity training has more potential than shorter-term creativity training in terms of improving creative capabilities.

When the results of the combined data were initially considered, without the insight of the comparative results, the data suggested that neither the short-term training nor the long-term training had any significant effect on the creativity of the participants involved. However, when the comparative results were referenced, a different conclusion was gathered. The results of the short-term creativity training (WB) showed no significant improvement was evident.

The analysis of the long-term creativity course pre-training (CA) and post-training (CB) results provided evidence that there were three characteristics improved, while another two continued their decline. This suggests that each set of characteristics overall negated the changes they experienced. The two negatively-affected sub scores within the CB scores were related to the decrease of analysis and synthesis. As discussed earlier, this may be due to several factors, particularly the limited scope of the provided training. The depth provided by the additional material provided by a graduate course in creativity at the University of Central Florida addresses these gaps by introducing immersion into creativity literature, in addition to visual arts immersion. Both aspects allow for a fuller understanding of creativity, and also emphasize not only the generation of inspired ideas, but also the analysis, synthesis and eventual completion of an idea.

The results of the creativity course seniors training (CA/CB) must also be integrated with the findings of the statistical analyses between the pre-training creativity course seniors (CA) and the creativity workshop seniors (WA). Those analyses pointed at the creativity course senior engineers (CA) as having already undertaken inadvertent creativity training, with an average

improvement of over seven points as compared to the pre-training creativity workshop scores (WA) as measured by the TCT-DP. Almost all sub scores were improved by this inadvertent training before the pre-test for the creativity course seniors (CA). As such, the results of the creativity course post-test (CB) point to improvement beyond an already significant improvement in creativity scores (CA), as compared to the pre-test creativity workshop seniors' scores (WA) who had received no training yet at all.

The inadvertent training is posited to stem from the known creative expectations of the course on the creativity course seniors, who were left in anticipation after the initial introduction to the course content. The four to six weeks of anticipation before the pre-test (CA) and the final test results (CB) indicate long-term expectations may play a vital role in creativity score improvement. Based on the study results, as well as the posited reasoning for the large sample differences between the pre-training creativity course seniors (CA) and the pre-training creativity workshop seniors (WA), there is sufficient evidence that longer-term creative training can significantly improve the creative capabilities of engineering students.

Additional support for this conclusion was suggested by an analysis of the average differences of improvement between the short-term and long-term groups. The study found that the long-term creativity group (CA to CB) gained more overall improvement from the creativity training than the short-term creativity group (WA to WB). This was the case even after the pre-training creativity course group (CA) was exposed to inadvertent creativity training. Long-term creativity training can indeed provide significant improvements in creativity even when the subjects have already received some level of training. The engineering curriculum must be updated to adopt this finding as a signal of the potential for continued improvements for student

engineers. Not only can creativity training provide benefit once, but it can continue to improve creative skills with longer exposure.

More research needs to be conducted in order to refine the creativity training approaches being taken and how the content affects students' creative performance. A study in the graduate-level creativity course within the University of Central Florida, EIN 6370, could provide a better understanding of how the curriculum affects the students, as well as determining if the extra content that exposes the students to artistic creative production provides further improvements in creative ability.

CHAPTER FIVE: CONCLUSIONS

Overview

The findings of this study exposed some very interesting insights in terms of engineering education and the potential of creativity training as a whole. The two experiments within the study asked some fundamental questions on creativity and critical thinking. Specifically, the experiments determined the initial condition of incoming freshmen, the current condition of senior students, and the potential outgoing condition of those students after specific creativity training was given.

The study results highlighted some known and unknown deficiencies in the engineering curriculum. This chapter presents the various conclusions and discussions layered within Chapter 4, with additional conclusions suggesting future work to improve on the results of this study. Each experiment is handled separately in order to better frame the conclusions based on the results being considered.

Experiment 1

The research questions answered by this experiment were: Are freshmen more creative than seniors, and are seniors better critical thinkers than freshmen? The experiment led to clear evidence that should be understood not only for its own significance, but also for its implications on traditional engineering instruction.

There is statistical evidence, within the $\alpha = 0.10$, that freshman engineering students (FA) outperformed senior engineers (WA) in creative skills, as measured by the TCT-DP. This suggests that engineers may be less creative when they graduate than they were when they began their degree of study program. In today's business world, companies that are unable to innovate

quickly are devoured by those who provide better solutions at a faster pace (Kouzes & Posner, 2012). Engineers with diminished creative capabilities are faced with challenges they are ill-equipped to handle. Where the 20th century saw process improvements and cost reductions in combination with innovation as a means to create competitive advantage, the 21st century workplace is targeting innovation as the only means of competitive advantage.

As previously mentioned, a report from the Partnership for 21st Century Skills revealed that employers found the incoming workforce lacking in many of the skills necessary to successfully work in modern business. Both creativity and innovation were on the advanced skill list of the essential skills employers identified as qualities they need from incoming workers. Though the four-year college entrants were found to be within the ‘excellent’ rating under this category, it was not by a large margin. With the results of this study strongly suggesting a decrease in overall creativity in engineers, these future working professionals may not be able to perform at the levels expected of them in an innovation-driven economy.

In addition to creativity, critical thinking performance was scored between the freshman and senior participants, as measured by the WGCTA. The research hypothesis for Experiment 1 stated that critical thinking performance would be higher for seniors (WA) than for freshman (FA) participants. This hypothesis was based on the natural problem solving inclinations of engineers, as well as several studies on critical thinking (Pascarella, 1987; Keeley S. M., 1992; Spaulding & Kleiner, 1992; Mines, King, Hood, & Wood, 1990). WGCTA normative data also supported this, as the upper-division students had significantly lower averages than freshman students (Watson & Glaser, 2008). The experiment’s results suggest a very different reality.

A statistical analysis of the critical thinking combined score data provided insufficient evidence that seniors (WA) better critical thinking skills than freshman engineers (FA) in

actuality. A sub score comparative analysis of the WGCTA results provided strong evidence that freshman engineers had better scores than seniors in one of the five WGCTA sub scores (Inference). There was also evidence in the $\alpha = 0.10$ interval of better performance in Evaluation of Arguments as well. Additionally, the participant groups' scores were compared against the normative data for their peer groups in the general population for all college majors, as provided by the WGCTA test. This led to an even more telling conclusion, regarding the effects of engineering education on critical thinking abilities.

The WGCTA results discussed in the Freshman and Senior Critical Thinking Results section in Chapter 4 show a significant problem for critical thinking in engineering beyond just stagnation. The incoming freshman engineers (FA) scored significantly higher in this area than average students within in their normative group. The senior engineering students (WA), on the other hand, scored significantly lower than their comparative normative sample. This evidence suggests engineering education is indeed having adverse effects on the critical thinking capabilities of engineers.

This may be attributable to the standard practice of book-based learning, which focuses on solving single-solution problems and general over-constraint due to the risks of engineering design. This process does not allow for general problem solving or critical thinking development, as the norms analysis strongly suggests. As such, the open format writing, discussion and engagement of other majors may actually be supporting their critical thinking skills better than the engineering curriculum is supporting that of its engineers (Kazerounian & Foley, 2007).

Engineering students are typically taught in a formulaic manner. A set of formulas related to the current topic are provided and questions are asked to test the student's ability to apply the formulas to the problem at hand. Additionally, engineering is considered a very serious and

conservative profession, as lives may be at stake if engineers take too many risks. These form a very enclosed and conservative atmosphere where risk may mean failure, which is looked at poorly within the academic setting. Douglas Wilde (1993) argued that engineering education inherently blocks the creative ability. The same study provides evidence that engineers are capable of creativity when in the right environment. Hadgraft's (1997) study also suggested that engineers are not inherently less creative than others. This idea is supported by the inadvertent creativity exposure experienced by the pre-training creativity course seniors (CA), wherein their creativity levels were measurably higher on the TCT-DP than those of seniors with no inadvertent creativity exposure (WA), merely because they knew of the course's future expectation that they provide creative solutions.

Engineering education lacks the flexible, playful and risk-taking environment needed for creativity and critical thinking to flourish. Without the possibility of experimentation, the engineering student assesses their coursework and profession as a place where exploration is inadvisable, as it can have negative repercussions for both their grades as well as the safety of others. Though this is true to a degree, exploration is essential in the development of critical thinking skills, as well as creative problem solving.

The employers who provided input for the report from the Partnership for 21st Century Skills also placed critical thinking skills as essentially necessary for success in the 21st century workplace (Casner-Lotto & Barrington, 2006). Of all the skills considered within the study (twenty overall skills), critical thinking was in the top five most important skills for new entrants with a four-year college diploma, as determined by employers in various fields. This makes critical thinking a major point of necessity for graduating seniors, as their ability to solve problems is paramount to their success within their professional field.

The results of this study suggested that freshman engineering students (FA) are more creative than senior engineering students (WA). Critical thinking was also shown to be stagnant between the two groups, and the scores of the seniors (CA) were degraded when compared to normative data. This may be due to three scenarios: the engineering curriculum had adverse effects, freshman students with high critical thinking and creative skills moved away from engineering, or a combination of both. These are serious concerns for the engineering profession that must be studied and addressed in order to not only keep talent but to nurture it through completion of an engineering degree. Both attrition and the unexplored educational causes affecting creativity and critical thinking need to be studied and addressed in order to start training engineers capable of innovation.

This experiment has not only further confirmed several findings in the existing literature, but has furthered our understanding of critical thinking in engineering students as well. The creativity decline is apparent in engineering undergraduates. Also, the experiment further confirmed the critical thinking stagnation findings of Douglas (2012) and Ozyurt and Ozyurt (2015); however, additional insight was evident when comparing the study data to normative data. Critical thinking actually significantly decreased in engineering senior students as compared to students in other majors. This finding is significant, as the problem solving capabilities of engineering students are declining. With real world engineering typically involving very limited boundary information, engineers are faced with challenges that cannot always be solved using the formulaic methods learned in the academic setting. Universities must provide their engineers with the means to be better prepared for the creative and critical thinking tasks they will face in real world engineering.

Experiment 2

The research question explored through Experiment 2 was: Is long-term creativity training more effective than short-term creativity training? The experiment's results provided an interesting look at not only short-term versus long-term creativity training, but also the potential usefulness of creative expectation and project-based curriculum on engineers. The results produced sufficient evidence that long-term training is more effective than short-term training.

One of the most interesting and unexpected results from the senior data was that the pre-training condition of both groups was significantly different. The equivalency of the two pre-training conditions between the creativity course seniors (CA) and the creativity workshop seniors (WA) was one of the original assumptions when the research question was developed. After finding differences of over seven points (on average) between their TCT-DP scores, further analysis was undertaken to determine if there was enough evidence that the creativity course seniors (CA) indeed scored higher on the test than creativity workshop seniors (WA). With very high certainty (P-Value = 0.000), the testing conditions were revisited to determine where the changes took place.

The creativity course seniors (CA) were administered the creativity testing six weeks after the commencement of their course. Based on the lack of specific creativity training between the beginning of the course and the creativity training portion, it was posited that the scores would not be significantly different from those of the pre-training creativity workshop seniors (WA). A theory was developed to address the large differences, harnessing existing studies on creative expectations and project-based curriculums. It was posited that, due to the students being informed of the creativity instruction and testing within the course to come at a later date,

their creativity scores were impacted merely by the expectation of being creative, even though it had not yet been required of them explicitly (Rietzchel, Nijstad, & Stroebe, 2014).

As discussed earlier, several studies suggest that creative expectation is a means of creativity improvement as well (Scott & Bruce, 1994; Tierney & Farmer, 2004; Shalley, 1995). Additionally, the level of creative expectation and the environment in which these expectations are implied has much to do with the creative production of participants.

Individuals develop their own expectations and acceptable behaviors based on the overall environment or climate of the workspace or educational setting (James, Hartman, Stebbins, & Jones, 1977). Based on these studies and their results, permission to be creative may be the true reason for the marked increase in creativity. There is strong evidence in research and industry that permission to be creative, including its associated failures, both through culture and environment, is very supportive of innovation (Kelley, Littman, & Peters, 2001; Starko, 2014; Twohill, 2012). By informing students of future creativity testing and creativity training, the professor implicitly gave students permission to be creative.

Additionally, it was determined that some students may have been exposed to one semester of senior design in the previous semester. This course had a strong emphasis on multidisciplinary project-based learning. Though project-based engineering has strong support as a means of creativity training, surveys have shown that engineering students did not believe they were taught creativity in any manner during their engineering education, including senior design (Kazerounian & Foley, 2007). Therefore, the impact of senior design is largely unknown. As such, a combination of these two creativity training techniques inadvertently provided training outside of the study-prescribed course training to the CA group. This is a very important finding, in that it supports long-term creativity training as an effective means of improving creativity,

when a project-based curriculum and creative expectation are used as creativity enhancement techniques.

The pre-training (WA and CA) and post-training (WB and CB) data for both senior groups was also analyzed to determine if the study-based creativity training had an effect on the senior students. The creativity workshop seniors' analysis (WA to WB) showed no evidence to suggest that the training had any appreciable effect on their overall creative skill. A comparative analysis of the creativity workshop seniors (WA to WB) provided no evidence of higher sub score performance. This suggests short-term creativity training is largely ineffective.

The statistical analyses of the creativity course seniors' data (CA to CB) suggested a different conclusion. The combined score analysis showed that there was not enough evidence to suggest the samples were different between the pre-training (CA) and post-training (CB) conditions. However, the comparative analysis did suggest that there were significant differences in several of the sub scores. Three of the sub scores (Bfd, Bfi and Uca) showed significant improvements due to creativity training. Two other significantly impacted sub scores (Cth and Pe) actually showed a statistically significant decrease in performance. This demonstrated that the long-term creativity training had a significant effect on the creativity of the participants.

The decline found in synthesis and analysis (Cth and Pe) in the CB scores may have been due to the methodologies used to enhance creative improvements. The focus of the training methodologies used within the creativity course supported divergent thinking and novel idea generation. The analyses suggest that the creativity training materials need to be reevaluated to determine if some portions may be having detrimental effects on synthesis and analysis due to an over-focus on divergent thinking methods. The graduate-level full course in creativity at the

University of Central Florida Engineering Department addresses these specific measures through the introduction of and immersion in both creative literature and visual arts.

Additional support for this conclusion was suggested by an analysis of the average differences of improvement between the short-term and long-term groups. The study found that the long-term creativity group (CA to CB) gained more overall improvement from the creativity training than the short-term creativity group (WA to WB). This was the case even after the pre-training creativity course group (CA) was exposed to inadvertent creativity training. Long-term creativity training can provide significant improvements in creativity, even when the subjects have already received some level of training. The engineering curriculum must be updated to adapt this finding as a sign of the potential for continued improvement for student engineers. Not only can creativity training provide benefit once, it can continue to improve the creative skills with longer exposure.

Long-term exposure to creativity training has significant impacts on the students' creativity. Based on the data collected, the longer individuals are exposed to creativity training, the more benefits they can garner from it. With modifications in the creativity training instruction, including the addition of synthesis and analysis improvement processes, the overall scores would be likely to improve. This is an additional benefit above the existing evidence of improvement, based on the inadvertent training discussed previously. Long-term creativity training improves creative skills in a measurable way when modified to better address many learning styles.

Creativity Course Performance versus Mapping Expectations

Table 4 mapped the TCT-DP variables to the creativity course content typically taught at the graduate level, EIN 6370 Innovation in Engineering Design. With results tabulated, the

measured sub scores of the TCT-DP for the creativity training course can be compared against the mapping criteria laid out within the reference table.

It was found that risk-taking and unconventionality were improved as a result of the creativity course training (Bfd, Bfi and Uca) in the scores of the CB group. This suggests that the course content linked to these individual traits was effective in influencing the students to improve their tolerance of risk and openness to experiences. The beach project, the classroom environment and readings appear to have positively affected the students' creativity.

Some of characteristics of creativity in the students continued their decline, even during the creativity course. Visualization and synthesis were not addressed by the deep dive session and the discussions within the course. Based on this information, a better approach for these, as well as for the other components of creativity that were unaffected, may be developed to better address the needs of the students. The graduate-level course includes additional activities in broadening creativity exposure, such as an impressionist art exhibit experience, which allows for more meaningful and immersive experiences. As discussed earlier, engineering students need permission to explore their creativity and these types of experiences may support that greatly.

These results must be considered in light of the inadvertent training which the pre-training senior engineering students (CA) undertook. When compared to the pre-training creativity workshop engineers (WB), the creativity course engineers (CB) performed significantly better. The creativity course seniors had better performance in eight sub scores over the workshop seniors in the post-training tests. It is argued that the improvements seen within the course (CB) are above and beyond those experienced early through the inadvertent training (CA). This training likely muted the results of the creativity course training program. As such, follow-

up studies are needed to calibrate the current content, as defined by Table 4, and understand the impact of continued improvements.

Conclusions

The experiments performed in this study provided unique insights into both the world of engineering education, as well as creativity training. The data exposed some problems that were expected, and also others that were not so immediately apparent. This section summarizes the conclusions discussed within this chapter.

Experiment 1 answered the first research question: Are freshmen more creative than seniors, and are seniors better critical thinkers than freshmen? The data showed evidence that incoming freshmen (FA) performed more creatively than senior engineering students (WA), as measured by the TCT-DP. It also provided no evidence that senior participants had higher critical thinking performance than freshmen. In fact, there was some evidence that freshmen outperformed seniors in critical thinking skills in two sub categories of the test. The results of the WGCTA results against the norms shed light on an even larger problem than the study results. Analysis results showed the study freshman ($\mu = 57.76$, $SD = 8.33$) entered their engineering education significantly above their group normative average ($\mu = 53.8$, $SD = 9.2$), up to the 70th percentile when compared to the normative data. On the other hand, the senior group ($\mu = 56.16$, $SD = 9.78$) was significantly below their normative group ($\mu = 59.2$, $SD = 8.4$), down to the 35th percentile when compared to their normative group. These findings provide strong statistical evidence that engineering education may be having a large detrimental effect on engineers.

As discussed in a previous section, Experiment 1 Results, the decrease in creativity and critical thinking stagnation suggested by the results may have been due to several causes. The traditional methodologies of engineering instruction and engineering student attrition may be the

main causes associated with these deficiencies. The traditional methodologies of engineering instruction may not only be negatively affecting students through their final year but it may also be contributing to attrition. It is necessary to understand the underlying effects of both of these causes in order to better address the problems they cause.

This experiment has further confirmed several findings in the existing literature, but also advanced our understanding of critical thinking in engineering students. The creativity decline is apparent in engineering undergraduates. Also, the experiment further confirmed the critical thinking stagnation findings of Douglas (2012) and Ozyurt and Ozyurt (2015), but additional insight was evident when comparing the study data to normative data. Critical thinking is actually significantly decreasing in engineering senior students as compared to students in other majors. This finding is significant, as the problem solving capabilities of engineering students are declining. This significant problem must be addressed through the development of critical thinking instruction, coursework development, and ultimately a restructured curriculum to better meet the needs of engineering students. Without these skills, engineers are unprepared and ultimately at a large disadvantage when they are faced with the challenges of a constantly-evolving world.

Experiment 2 addressed the second research question: Is long-term creativity training more effective than short-term creativity training? Through statistical analyses based on the collected data, little evidence exists that short-term creativity training improved overall creative skills (WA to WB). Short-term training did not provide the level of engagement necessary to fully benefit from the creativity characteristics the training was intended to influence. It can be argued that long-term creativity training (CA to CB) provided the time exposure and engagement that allowed participants to not only understand creativity as a beneficial tool, but to understand

they are capable of creative acts. This seems to be the driving force in creative skill improvement. The goal is to bring the students into a situation that makes them aware of their own creativity. This allows them to acknowledge that they are capable of performing creative works, making them more likely to embrace creativity in the long-term (Baillie & Walker, 1998; Vzyatishev, 1991). Project-based curriculum, creative expectation and creativity training programs provide a creative environment which allows students to explore, experiment and come to that conclusion over time.

Long-term exposure to creativity training has significant impacts on the students' creativity. Based on the data collected, the longer individuals are exposed to creativity training, the more benefits they can garner from it. With modifications in creativity training instruction, including the addition of synthesis and analysis improvement processes, the overall scores would likely improve. This is an additional benefit above the existing evidence of improvement, based on the inadvertent training discussed earlier. Long-term creativity training improves creative skills in a measurable way when modified to better address many learning styles.

Actions must be taken to determine and address deficiencies in the engineering curriculum and the loss of freshman with high creative and critical thinking skills. These deficiencies directly result in the stagnation of critical thinking and a degradation of creative abilities. The curriculum must support engineers in growing their capabilities in such a way that the resulting education prepares them for the real world work they are bound to perform. Focused courses that address creativity and critical thinking can provide a stop-gap measure to address these issues in the short-term, but more long-term solutions are ultimately necessary. A restructuring of the engineering curriculum that incorporates creativity-focused instruction is needed to provide a holistic experience. Project-based collaboration, creative engineering design,

and instruction focusing on problem definition and solution are just the beginning on the path towards addressing the issues exposed through this research. The engineering curriculum requires change that not only teaches engineering fundamentals, but also emphasizes novel solutions by solving the real problems engineering is intended to solve.

CHAPTER SIX: FUTURE WORK

The study discussed by this dissertation provided important insights on the standard engineering curriculum, as well as on methods of creativity training. Many questions were unearthed as a result of the conclusions drawn from the collected data as well. This section addresses those questions by suggesting areas that require further research in order to better understand the interactions between engineering education, creativity training and critical thinking training.

Engineering Creativity

Engineering creativity is a wide-ranging topic. This study focused on creativity training and how it can improve engineering design and problem solving. The inadvertent training undergone by the creativity course seniors (CA) initiated many questions that will need to be answered in order to better understand the techniques that contributed to a significant increase in their creativity scores, as measured in the differences between the two pre-training senior participant groups (CA and WA). Some of the questions brought to the forefront due to these results are:

- What aspects of creativity are directly influenced by project-based learning?
- Can additional creativity training techniques allow for increased creativity improvement in students already exposed through project-based creativity training?
- What effect does creativity expectation have on creative practice?
- Do the combined effects of creative expectation and exposure to project-based curriculum have a larger effect on creativity than either would individually?

- Can the improvements seen from creativity expectation be improved upon further with additional creativity measures?
- Can additional creativity techniques overcome the analysis and synthesis degradation seen in the creativity course pre-training and post-training comparative analysis results?

By addressing these questions, a better understanding of project-based training and creative expectation could help build more effective creativity training programs, as well as a better engineering curriculum. By incorporating these relatively simple additions into the existing engineering curriculum, great improvements in creativity may be possible at a relatively low level of impact to the existing curriculum. This may only be a stopgap measure to address the decline of creativity, but it can provide a means of moving expeditiously toward more significant changes that will ultimately benefit everyone.

Long-term solutions to most effectively address the creativity deficits in the engineering curriculum must be found. In order to do so, some additional questions must be investigated and understood. These questions explore how creativity training affects students over longer periods, how multidisciplinary work influences engineers' creativity, and understanding how an increased level of expertise can better support creativity. Some questions that must be researched to understand the longer-term effects of creativity are:

- How does creativity training affect freshmen?
- How does it affect their creativity over long periods of time?
- Does continuous exposure to creativity training techniques provide continued improvement of creative abilities?
- What training techniques support increased risk-taking in creative solution generation?

- How do increased levels of expertise affect creativity, and do they lead to an increased willingness to take creative risks?

Though the study conducted within this dissertation did not directly involve the arts in the creativity training, the graduate-level course that provided the framework for the longer-term undergraduate creativity training course used here provides immersion in the visual arts as a technique to strengthen synthesis and analysis measures in students. Other studies have concluded that when medical students are provided with artistic visual training techniques, their observational skills significantly improved in real world scenarios (Bardes, Gillers, & Herman, 2001; Klugman, Peel, & Beckmann-Mendez, 2011; Naghshineh, et al., 2008; Shapiro, Rucker, & Beck, 2006). These results indicate there may be potential benefits in allowing artistic and engineering students to work together in multidisciplinary teams, in order to allow for cross-discipline learning. The integration of art and engineering is addressed through efforts such as STEAM learning, which argues that in addition to science, technology, engineering and mathematics, art can provide essential skills that are necessary to excel in the other areas. This branch of creativity training may provide benefits not yet tested in the engineering educational setting. Some research questions that would allow for a better understanding of the effects of art on the STEM fields are:

- Can visual training for artists support engineers in developing creative solutions?
- How does exposure to creative majors in a project-based curriculum affect engineers?
Additionally, how does it affect the creative majors?

By exploring the questions mentioned here, researchers may reach a better understanding of how creativity training can be used to develop more effective training approaches. By

focusing on improving creativity training and supporting engineering students in their pursuits, engineering design can evolve and more novel products can be accessible to everyone.

Critical Thinking in Engineering

The study results suggested that critical thinking skills were stagnant, even after a significant portion of the engineering curriculum had been completed by the participants (FA vs. WA). These results are worrying, as engineers are typically employed to solve the problems of industry. Critical thinking skills must be developed in engineers in order to better prepare engineering students to overcome the open-ended problems constantly encountered in real world engineering. There is evidence that critical thinking can be taught through instruction, training and experience (Dominguez, et al., 2015; Ralston & Bays, 2015). Some research questions that will allow for a better understanding of how critical thinking is impacted by age, instruction and evaluation are:

- What techniques build critical thinking processes?
- Does exposure to project-based instruction impact critical thinking ability?
- Does exposure to philosophical logic coursework improve critical thinking skills used in engineering?
- Does age have a direct impact on critical thinking skills? Is there a downward trend from 19-29 with an increasing trend thereafter, as suggested by the study data?

In addition to these more general research questions on critical thinking, there are other paths to understanding and teaching critical thinking skills. Studies in cognitive psychology point to interesting approaches in learning and problem solving that may be applicable to critical thinking instruction. Roediger and Karpicke (2006) showed that a combination of studying and content testing is a means to improve the retention of learned information. A review of existing

literature even suggested that, “recall testing of previously studied information can enhance learning of subsequently presented new information” (Pastotter & Baumi, 2014). Additional avenues toward improved critical thinking and problem solving exist, such as incubation, and must be explored to determine the best approach to instruction in these vital skills.

Creativity and critical thinking are essential tools for engineers. Without them, engineers may face challenges that they are ill-prepared to solve. By better understanding the various aspects of creativity and critical thinking as discussed here, engineers can improve their problem solving performance. This is not only beneficial for these individuals, but is bound to also provide benefits to everyone through their resulting ground-breaking discoveries and solutions.

APPENDIX A
UCF IRB APPROVAL



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Approval of Exempt Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Eric O. Sola**

Date: **May 27, 2015**

Dear Researcher:

On 05/27/2015, the IRB approved the following activity as human participant research that is exempt from regulation:

Type of Review:	Exempt Determination
Project Title:	AN EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF SHORT VERSUS LONG TERM CREATIVITY TRAINING ON THE INNOVATION POTENTIAL OF UNDERGRADUATE ENGINEERING STUDENTS
Investigator:	Eric O Sola
IRB Number:	SBE-15-11291
Funding Agency:	
Grant Title:	
Research ID:	N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the [Investigator Manual](#).

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 05/27/2015 10:56:28 AM EDT

IRB manager

APPENDIX B
UCF IRB ADDENDUM APPROVAL



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Approval of Exempt Human Research

From: UCF Institutional Review Board #1
FWA00000351, IRB00001138

To: Eric O. Sola

Date: August 28, 2015

Dear Researcher:

On 08/28/2015, the IRB approved the following minor modification to human participant research that is exempt from regulation:

Type of Review: Exempt Determination
Modification Type: The location for the Freshman testing portion of the study needs to be changed. A revised protocol and other study documents have been uploaded in iRIS. A revised consent document has been approved for use.
Project Title: AN EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF SHORT VERSUS LONG TERM CREATIVITY TRAINING ON THE INNOVATION POTENTIAL OF UNDERGRADUATE ENGINEERING STUDENTS
Investigator: Eric O Sola
IRB Number: SBE-15-11291
Funding Agency:
Grant Title:
Research ID: N/A

This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these changes affect the exempt status of the human research, please contact the IRB. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

In the conduct of this research, you are responsible to follow the requirements of the [Investigator Manual](#).

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

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