12-2016

# The association between tolerance for ambiguity and fear of negative evaluation: A study of engineering technology capstone courses

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*30 Updated 12/26/2015*

**PURDUE UNIVERSITY**
**GRADUATE SCHOOL**
**Thesis/Dissertation Acceptance**

This is to certify that the thesis/dissertation prepared

By Sergey I. Dubikovsky

Entitled

THE ASSOCIATION BETWEEN TOLERANCE FOR AMBIGUITY AND FEAR OF NEGATIVE EVALUATION: A STUDY OF ENGINEERING TECHNOLOGY CAPSTONE COURSES

For the degree of Doctor of Philosophy

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# THE ASSOCIATION BETWEEN TOLERANCE FOR AMBIGUITY AND FEAR OF NEGATIVE EVALUATION: A STUDY OF ENGINEERING TECHNOLOGY CAPSTONE COURSES

A Dissertation

Submitted to the Faculty

of

Purdue University

by

Sergey I. Dubikovsky

In Partial Fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

December 2016

Purdue University

West Lafayette, Indiana

This work is dedicated to my wife, Nadya, with my gratitude for her tolerance and support throughout my study.

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# ABSTRACT

Dubikovsky, Sergey I. . Ph.D., Purdue University, December 2016. The Association between Tolerance for Ambiguity and Fear of Negative Evaluation: A Study of Engineering Technology Capstone Courses. Major Professor: Matthew Ohland.

For many students in engineering and engineering technology programs in the US, senior capstone design courses are mandatory for graduation. Also, the same courses are required by accreditation bodies such as ABET, Inc. and others. The students must form a team, define a problem, and find a feasible technical solution to address this problem. In other words, students must demonstrate the knowledge and skills acquired during their studies at the college or university level. In reality, however, there are many additional non-technical, so-called "soft" skills, present in such projects. The most prominent example is that the majority of the listed steps do not have a single "correct" resolution. Instead, there is an array of solutions, many of which could be successfully used to achieve the final result. This situation creates roadblocks and anxiety during the projects.

This study examined the main topics:

- What is the association between tolerance for ambiguity and fear of negative evaluation at the beginning and the end of engineering technology capstone courses?
- How does exposure to ambiguity prior to capstone courses and during them affect tolerance for ambiguity?

The study looked at the standard educational practices to see if they have unintended consequences, such a social anxiety in dealing with ambiguity. Those consequences are highly undesirable because they reduce students' learning. It was hypothesized that the lecture-based approaches that are more common in the first three years of study would not prepare students for self-directed capstone courses because the students would rarely have experienced problem-based learning before.

The study used a quantitative approach and examined students' perceptions of their tolerance for ambiguity, and social anxiety before and after their senior capstone design experience. A survey instrument was adapted to measure exposure to ambiguity, which was studied as a potential moderator of the relationship between social anxiety and tolerance for ambiguity.

The study indicated that social anxiety, as measured by fear of negative evaluation, does not play a major role in capstone courses. The second finding is that a single course, even if it was administered as a problem-based senior class, failed to increase students' tolerance for ambiguity. Students with low tolerance have more problems with ambiguity, whereas students with high tolerance can more easily endure changes and find it easier to act in the absence of complete information. The third important finding was that exposure to ambiguity prior to capstone courses does affect tolerance for ambiguity while controlling for instructor and if exposure to ambiguity is included as a moderator. It was not in the scope of this study to explore the effect of instructor more deeply, but this provides a direction for future research, especially in this time of expanding implementation of project- and problem-based learning methods in technical curricula.

# CHAPTER 1. INTRODUCTION

## 1.1 Statement of the Problem

What is the association between tolerance for ambiguity and fear of negative evaluation at the beginning and the end of engineering technology capstone courses? How does exposure to ambiguity prior to capstone courses affect tolerance for ambiguity? Tolerance for ambiguity and anxiety are widely researched in the medical and management fields. In engineering and engineering technology, however, these concepts are much less explored, despite the fact that engineering is ambiguous and uncertain by its very nature. Koen (2003) defined the engineering method as "the strategy for causing the best change in a poorly understood situation within the available resources" (p. 7). Examples of those resources are limited time, lack of absolute knowledge about the world and how it relates to society's wants and needs. Despite the fact that there have been years of studies by psychologists, management experts, and educators, the field of ambiguity and its role in education is mostly still unknown and not well understood (Atkinson, 1984; *Fox, 1957;* Katz, 1984; Simpson, Dalgaard, & O'Brien, 1986). The guidance of an experienced instructor and the opportunity to receive first-hand experience through practical and useful active learning projects helps to reduce or maintain both ambiguity and uncertainty

(Klahr & Nigam, 2004; Mayer, 2004). As another benefit, students learn how to use many available industry methods and tools when dealing with those topics (Dubikovsky & Kestin, 2012).

## 1.2 Context and Background

Tolerance for ambiguity was originally treated as a personality trait, which means that the same person in different situations demonstrates the same tolerance (Adorno, Frenkel-Brunswik, Levinson, & Sanford, 1950). It was also initially believed that the ability to tolerate ambiguity is a part of a person's innate personality (Feather, 1971; MacDonald, 1970; Trapnell, 1994). However, William Scott (1966, 1969) did not agree with this approach and, together with Durrheim and Foster, offered their theory where tolerance for ambiguity could be situation-specific. According to these later and well-received investigations, if an individual is intolerant of ambiguity in one specific situation, it does not necessarily follow that he or she is ambiguity-intolerant overall (Durrheim, & Foster, 1997). Koretsky et al. (2011) moved even further and demonstrated that some interventions and activities have the ability to, in fact, improve tolerance for ambiguity. The current study is based on findings of those researchers and subjects were chosen from senior engineering capstone classes of students from Purdue University's Polytechnic Institute. The courses were required for the ABET TAC-accredited degree programs. These students have knowledge of using hand tools and equipment like lathes, milling machines, band saws, and hand tools. At the capstone stage they needed to participate in the generation of new designs and to produce tangible products. The capstone courses are often the only classes where it is possible to demonstrate everything the students learned during their degree program study; such as knowledge of aircraft or other systems and how they function together, metallic and composite material science, testing, design and manufacturing processes, and metal cutting.

### 1.3 Purpose and Objectives of the Study

The purpose of this study was to (1) analyze students' perceptions during a problem-based engineering capstone experience, (2) describe how this experience relates to anxiety and tolerance for ambiguity, and (3) determine the association between tolerance for ambiguity and fear of negative evaluation in senior capstone courses. This information could be used to develop many forms of active learning in preparing students for the workplace, and provide a basis for further research.

### 1.4 Significance of the Problem

Now, more than ever, engineers are exposed to an ever-changing world and rapid development of new technologies (Augustine, 2005; Christensen, 1997). The global economy plays an especially important role in this fluidly-changing environment (ASEE, 2010; Ayokanmbi, 2011; Dossani, & Kenney, 2006; Farrell, Laboissie`re, & Rosenfeld, 2006; Leiblein, 2003; Lewin, & Peeters, 2006; Maskell, Pedersen, Petersen, & Dick-Nielsen, 2006). The American Society for Engineering Education (2010) summed this up in the Green Report: “the practice of engineering is now global (p. 3).” Practicing engineers must be extremely adaptive, mentally flexible and possess high tolerance for ambiguity and maintaining low levels of anxiety to be successful in the current world (Schwartz, & Bransford, 1998; Schwartz, & Martin, 2004). This brings an importance to this issue in the college and university environments. Some researchers indicated that intolerance of ambiguity is a personal trait and could be altered (Durrheim, & Foster, 1997; Koretsky, Kelly, & Gummer, 2011; Scott, 1966, 1969), yet there is also strong opposition to this point of view (Feather, 1971; MacDonald, 1970; Trapnell, 1994). Management and medical programs employ teaching methods to improve tolerance for ambiguity (Foxman, 1976; Geller, Faden, & Levine, 1990; Hmelo, 1997; Katsaros, & Nicolaidis, 2012; Rotter, & O'Connell, 1982; Schere, 1982), but engineering and engineering education is lagging in this field. In most cases, active learning, including project- and problem-based methods, is used to deliver the desirable outcome. Based on constructivism (Perkins, 1991; Piaget, 1969; Vygotsky, 1978) and according to many researchers (Dewey, 1938; Kilpatrick, 1918, 1921), active learning is an excellent method, but it does have its own pitfalls, one of which is that students may not be successful or perform well on something they do the very first time (Chi, DeLeeuw, Chiu, & LaVancher, 1994; Lesgold, Rubinson, Feltovich, Glaser, Klopfer, & Wang, 1988; Novick, & Hmelo, 1994;). To make the matter worse, often intricate relationships between long-term and working memories are ignored in human cognitive architecture during active learning activities, which could potentially lead to an ineffectiveness of any form of active learning. Learners' long-term memory is altered through their working memory (Kirschner, Sweller, & Clark, 2006). Another aspect is that the human memory is unable to process a large amount of information at one time (Kirschner, Sweller, & Clark, 2006).

An instructor serves as a facilitator during any type of active learning and careful design of learning activities is another factor that must be considered (Greeno, Collins, & Resnick, 1996; Hmelo-Silver, 2002; Hmelo-Silver, & Barrows, 2006; Koschmann, Myers, Feltovich, & Barrows, 1994). Frequently, these factors are ignored during implementation of problem- and project-based learning activities and this fact has gone unnoticed because of a lack of direct measurement of the effectiveness of active learning activities (Dods, 1997; Norman, Brooks, Colle, & Hatala, 1998).

The Six Sigma methodology and various project management tools are widely utilized in many industries to reduce uncertainty and ambiguity by applying a systematic and logical approach, by slicing a big problem into smaller, better managed pieces (Dubikovsky, & Kestin, 2012). An opportunity for students to actually work on a real product, process, or/and service under the guidance of an experienced and educated instructor, provides first-hand experience on how to reduce both ambiguity and uncertainty and how to use many available tools when dealing with these topics.

## 1.5 Research Questions

This study examined the main topics:

- What is the association between tolerance for ambiguity and fear of negative evaluation at the beginning and the end of engineering technology capstone courses?
- How does exposure to ambiguity prior to capstone courses and during them affect tolerance for ambiguity?

## 1.6 Definitions

Yurtsever (2001) defines tolerance for ambiguity as "the extent to which an individual feels threatened by an ambiguous situation." If a situation is not fully and clearly defined, individuals with high tolerance for ambiguity perform better and experience less anxiety than those with low tolerance for ambiguity.

The terms *uncertainty* and *ambiguity* are often used interchangeably. Both of those concepts have similar physiological effects, but those terms are not exactly the same. Their time frame separates them: *ambiguity* is connected to the present and *uncertainty* refers to the future.

## 1.7 Limitations

This study concentrated on yearlong senior capstone design courses in the School of Aviation and Transportation Technology and School of Engineering Technology (Aeronautical Engineering Technology, Mechanical Engineering Technology and Electric Engineering Technology programs) of Purdue University. It was determined that an active learning approach would be the best way to assess the outcomes in question. This is in part because highly structured lecture-based courses do not leave many options to introduce uncertain or ambiguous situations. The initial number of participants was 150; most of them were 20-22 years old. The study took place throughout two semesters of senior engineering capstone courses. The first semester was the proposal stage of a design, with implementation of the design during the following semester. The researcher was an instructor in one of those courses, but not in all.

# CHAPTER 2. LITERATURE REVIEW

## 2.1 Uncertainty vs. Ambiguity

Though one maybe be tempted to use the words *uncertainty* and *ambiguity* interchangeably, it is important to understand that they are not the same. The terms *tolerance for ambiguity* and *tolerance for uncertainty* do, however, have similarities. The first of these similarities is that both mean a person's tendency to consider particular situations as a source of discomfort or as a threat (Kirton, 1981, MacDonald, 1970, McLain, 1993, Furnham, 1994; Krohne, 1989, Ladouceur, Gosselin, & Dugas, 2000). Another similarity is that in both cases individuals respond to threat or discomfort with emotional, cognitive, and behavioral feedback (Bhushan & Amal, 1986; Freeston, Rhéaume, Letarte, Dugas, & Ladouceur, 1994).

The main difference between these terms lies in the time frame. *Ambiguity* is applied to the present while *uncertainty* assumes a future situation. This means that individuals with intolerance for ambiguity treat a current situation for which they perceive they have insufficient information as a threat; people with intolerance for uncertainty are affected by an unpredictable situation, which has the potential to occur in the future. Both conditions lead to anxiety and discomfort though the timeline differs.

## 2.2 Ambiguity/Uncertainty as Inherent in Engineering

As Koen (2003) described, ambiguity and uncertainty is a central part of engineering and its methods. Koen defined the engineering method as "the strategy for causing the best change in a poorly understood situation within the available resources" (p. 7). To understand this definition better, one must look at all of its components.

Thus, the engineer is required to see opportunities for change and to act as a vehicle for this change. Yet, as Koen points out, the engineer can never fully understand the complexity of the system being changed because the engineer does not have absolute knowledge of it. The second challenge is that one of the missing pieces of understanding is that the engineer does not know the best way to achieve the goal of implementing a change, so any attempt at change could lead to unintended consequences. In practice, then, an engineer must set out to cause change with a set of certain limitations and assumptions, as well as consider some ideas about how this change would fulfill the *needs* or *wants* of society. The third challenge is that those *needs* or *wants* could change at any moment for a multitude of reasons. The fourth and last challenge is that society, in general desires certain products or services; however, it is never clear that individuals actually want those results. In addition to the ambiguity and uncertainty as to how to cause *change*, there is uncertainty in the end goal based on what is meant by *best*. Resource limitations preclude aspiration to Plato's definition of "best" and required the engineer to consider a more practical approach in place of "an ideal, perfect form of, say, beauty, justice, or whatever is an ultimate best and then considering approximations to this form as better and better as they approach this ideal" (Koen, 2003, p. 15). Instead of finding the perfect solution, the engineer must "settle" for a workable and optimum one. However, this found solution might not be transferrable to another unstructured problem. Further, the solution must also fulfill a multitude of criteria, not just one. These requirements often, but not always, conflict with one another. A good example would be a lightweight aircraft that is durable, and has good structural strength. The first requirement does not match the last two but all of them could be equally important. Aeronautical engineers must deal with this kind of dilemma. Another example would be a conflict between desired complexities of a device's performance and ease of its operation, as seen in modern cell phones, digital cameras, and other products. All of those conflicting requirements, *needs*, and *wants,* increase the ambiguity inherent in the engineer's work.

Because of limited *resources*, the engineer must find a compromise, given some ambiguity and uncertainty, for an optimum solution while meeting an acceptable level of the design requirements by employing mathematical modeling to foresee desirable results. Evaluation of the **"best"** has turned into a well-defined procedure in a social context:

> "Unlike science, engineering does not seek to model an assumed, external, immutable reality, but society's perception of reality including its myths and prejudices. … Likewise, the engineering model is not based on an eternal or absolute system, but on the one thought to represent a specific society." (Koen, 2003, p. 18-19)

Several complications and ambiguity also arise when an engineer must join a team to perform, but must simultaneously create individually on her or his own. In the modern world economy, the engineer could work on fulfilling needs of the society with other professionals all over the globe, but this situation increases ambiguity and uncertainty: How would the engineer fit in the team? How would he or she handle a different culture, be it company rules or ethnical differences in the other country? Philosophically speaking, engineering artifacts are reproduced in the “dual nature:” through *functional* and *structural* modes (Bucciarelli, 2003).

All of those challenges are present in a senior engineering capstone course, yet the students generally do not possess enough experience and knowledge to handle the issues without the guidance of an experienced instructor.

## 2.3 Ambiguity/Uncertainty and Engineering Process/Engineering and Design Problems

Cross (1984) described engineering problems as “ill-structured” and “wicked.” They are based on a wide range of assumptions, which are made by designers. Design problems are underdetermined, where there is not a closed pattern of reasoning connecting needs and requirements of the project with a resulted artifact (Dorst, 2003). Roozenburg and Eekels (1995) argued that requirements, intentions and needs are impossible to finalize completely. Another difficulty lies in the fact that those concepts don’t even exist in the same “conceptual world” with structures (Meijers, 2000). In other words, information for a design is incomplete and open to interpretation by a designer. This interpretation is done throughout the design process, which consists of many steps. During each phase, certain assumptions are made and solutions are found based on those requirements. Also, many interpretations are driven by a designer with his/her own preferences and experiences (Dorst, 2003).

Epistemologically, design problems are based on both positivism and phenomenology, which are the opposite sides of the philosophical spectrum (Coyne, 1995, Varela, 1991). On one hand, positivistic epistemology drives the rational problem solving component. On the other hand, reflective practice lies in the nature of phenomenology. Schon (1983) described reflective practice as “the artistic, intuitive processes which some practitioners do bring to situations of uncertainty, instability, uniqueness, and value conflict." According to the positivistic point of view, an individual exists in an objective world and learns about it through his or her senses. However, the phenomenological approach dictates that a person is dynamic and is influenced by an environment and how he or she perceives it. In this case, it is impossible to disconnect a person and an object (Merleau-Ponty, 1962). According to Gadamer (1986), interpretation is a tool to connect the gap in the dual nature of design problems. That brings us to situated problem solving, where all design problems can only be seen through a designer’s point of view and senses (Varela, 1991).

Design process addresses a future as it was reflected by Gregory (1966):

> “The scientific method is a pattern of problem-solving behavior employed in finding out the nature of what exists, whereas the design method is a pattern of behavior employed in inventing things...which do not yet exist. Science is analytic; design is constructive.”

In his *Designerly Ways of Knowing*, Cross (1982) has identified five facets of design: “(1) Designers tackle 'ill-defined' problems, (2) Their mode of problem-solving is 'solution-focused'; (3) Their mode of thinking is 'constructive'; (4) They use 'codes' that translate abstract requirements into concrete objects; (5) They use these codes to both ‘read’ and ‘write’ in ‘object language” (p. 226).

From those aspects, he justified three main areas for design in education:

- “Design develops innate abilities in solving real-world, ill-defined problems.
- Design sustains cognitive development in the concrete/iconic modes of recognition
- Design offers opportunities for development of a wide range of abilities in nonverbal thought and communication” (p. 226).

Those areas are very applicable to a senior design course. Open-ended problems without a definite correct solution are complicated by working in a team environment under guidance of an instructor.

### 2.4 Engineering, Intellectual Development, Design, and Ambiguity

There is a strong relationship between undergraduate students’ intellectual development and the Perry Scheme of Intellectual and Ethical Development (Perry, 1999), which is widely used to analyze students’ epistemic cognitive development in a college environment. It was developed by William Perry during his tenure at Harvard University’s Graduate School of Education. He limited his research to examining undergraduates throughout their studies (Harvard Office of News and Public Affairs, May 27, 1999). According to Perry, each person has an opportunity to move through four stages in his or her development during their lives. It starts with the dualism stage where everything is black and white, good or bad, right or wrong (Perry, 1999; Prichard, &

Sawyer, 1994). At this stage an instructor is viewed by majority of learners as an absolute carrier of knowledge; the role of a student is to work hard and receive facts from a professor. This point of view changes at the multiplicity stage, where some students start to treat information from an instructor with respect, but realize that it is open for interpretation. Knowledge is not black and white anymore and uncertainty is acknowledged. At the third stage, contextual relativism, some students shift responsibility of learning from the instructor to themselves. Most undergraduates stop at this stage of the process and very little progress to the final stage: commitment in relativism, where knowledge and ethical choices become inseparable. It is worth noting that most studies which used the Perry Scheme of Intellectual and Ethical Development are concerned with the dualistic to multiplicity transition.

For example, Carmel-Gilfilen and Portillo (2010) examined the evolution of design criteria in 32 undergraduate students in an interior design program at a large public university. The authors employed two instruments: the Measure of Intellectual Development (MID) and the Measure of Designing (MOD). Both tools were administered in the form of essays, assessing different aspects of experiences. Three major approaches were found: a) prescribed method, where students view design criteria as the driving force for solutions and options. In this approach, the students were "stuck" on a basic solution and did not reach full potential; b) foreclosed approach, where students saw criteria as a block to creativity; and c) integrated method, where students realized more than one criterion existed in their design. However, it should be noted that even the integrated group had difficulty weighing the criteria. The first two methods were employed mainly by dualistic thinkers; the last one was used primarily by multiplistic thinkers.

The main finding of this particular study was that the researchers established a relationship between the Perry model and the way students perceive and approach design tasks, such as (1) the design process itself, (2) selection of assumptions, (3) acceptance of limitations and specific design steps, as well as (4) evaluation of design. A clear progression of development from black and white extremes to a multitude of ways to understand knowledge was observed in both design-oriented and global thinking. It was also noted that this progression was related directly to the number of years in college. Most freshmen demonstrated dualistic thinking, while many seniors moved to the multiplistic stage, which is consistent with previous studies in the field (Kitchener, & King, 1989). At the same time, some students learned that criteria are not simple sets of rules and are not a limiting factor for creativity. Those students demonstrated integration of different criteria into a final design with a multitude of options. However, students who practiced the prescribed method still viewed assumptions as an absolute and non-negotiable requirement and never reached their potential in creative design. Also, dualistic thinkers generated a limited a number of design criteria as well, which reduced innovation and creativity.

Wise, Lee, Litzinger, Marra, and Palmer (2004) performed a four-year longitudinal study at the Pennsylvania State University, University Park campus. The authors studied undergraduate students' intellectual development throughout their tenure at the institution using the Perry Scheme of Intellectual and Ethical Development (Perry, 1999). The goal of the study was to answer the question: "What is happening as far as intellectual change with our engineering undergraduates?" (Wise, Lee, Litzinger, Marra, & Palmer, 2004, p. 109). The researchers used a semi-structured interview approach because it proved to be the most appropriate and allowed collection of the richest data. In first two years in the engineering undergraduate programs at the university, the participants of the study were mostly exposed to large, lecture-based classes. The first design course, which provided hands-on and problem-solving opportunities in a team environment, was offered for students' third year. The researchers noted a significant difference in Perry scores between students who took this design course and those who did not. This was attributed to real-life projects with industry involvement, where the participants were exposed to ambiguity by nature of the projects. Strict and well-defined requirements and expectations of familiar lecture-based courses were replaced by the engineering open-ended problems. Also, it was found that those measured differences disappeared between the first and third interviews three semesters later.

Using an analysis of variance (ANOVA), the main finding was that the student's school year has a significant effect on Perry ratings, which is consistent with the Perry model. Because of the strong "school year factor" (Wise, Lee, Litzinger, Marra, & Palmer, 2004, p. 107), additional ANOVA Bonferroni test revealed significant variance between the first and the fourth years, as well as the third and the fourth years. Very little intellectual growth happened during the second year. The researchers think that this is because most courses during this year were organized in such a way that the instructor appeared to be an authority person and tended to transfer his or her knowledge through lectures to students who were passive recipients of information. It is worth noting again that the first design course is offered only on the third year in the engineering programs in addition to specialized engineering classes. The third year is also a year when students entered their majors. According to the Perry scheme, the situation with only lecture-based courses is less beneficial to learning. The increased growth in the last year was explained by the researchers that teamwork and project-based learning drove the students' intellectual development.

Downey and Lucena (2003) took a different approach in studying team interactions and students' design experience. They concentrated on understanding engineering students' difference between science and design to improve engineering education. They found that incoming engineering students don't make a distinction between those two concepts. Also, the researchers found that "students learning engineering problem-solving experience a challenge to make themselves invisible in engineering work" (Downey, & Lucena, 2003, p. 170). Downey and Lucena provided practical observations. For example, they witnessed the struggle of the research subjects with initial problem definition, even though this was a major element of the design experience and was required for successful completion of the course. This confusion was overcome by doing research and specifying main terms and conditions. Another "stumbling block" was treating the course as a two-credit hour class only with no or very little individual study outside of the course. The students also limited design concepts to a major-specific science and efforts to "make it fit," and to dismiss the instructor's suggestions to open up those major-specific solutions to other fields of engineering, to explore options outside of students' expertise. At the same time, the students treated the instructor as an "absolute authority" by concentrating their efforts to explore the professor's ideas only. Another challenge lies in attempting to treat the senior design course as a regular engineering course, where students concentrate on typical assignments like homework, quizzes, and tests. These activities are usually scheduled and administered by an instructor and don't need students' input and effort to stay on track throughout a semester. The authors noted that one of the teams spent on average 15 minutes a week on the project instead of the six hours required by the syllabus. Most of the work was done in the last few days of the semester end.

In sum, the students tried to employ the same approach of simply following instructions and lectures, and structured class activities for engineering design as they did for engineering science and problem-solving in mathematics. For example, a few major elements of the engineering practice and knowledge went unnoticed by some students, because those tasks were not specifically designated as gradable assignments. To make the issue even more difficult, design is not governed by a single equation like in many engineering sciences and, in many cases, cannot be reused for different applications. Those issues led some students to believe that the design experience was a waste of time. In other words, many students demonstrated attributes of dualistic learners, who accept a black-and-white view of the world where there is no variety of options available to achieve innovative solutions to open-ended problems. However, other students did realize that, even when a design is about individual choices, it is based on engineering knowledge. In this case, those students showed attributes of multiplistic thinkers and understood the complexity of the design process, which led to creative solutions.

All of those findings, according to Downey and Lucena, prove that there is disconnect between engineering design and engineering science. The students misunderstand design process as a creative and open-ended activity, which depends on multitude of options, requirements, and assumptions. As a solution to this disconnect, per the researchers, adding more design courses in the first year of an engineering program is beneficial, but curricula must also follow and include recent changes in science as well. As the authors put it, educators must realize that “engineering practice necessarily involves working and engaging in problem solving with others who define problems differently than one does” (Downey, & Lucena, 2003, p. 174).

As intellectual development continues after graduation, so do graduates’ interpretation of design. Former students find jobs and slowly become experts in specific fields, including design. How does this happen? Ahmed, Wallace, and Blessing (2003) undertook a study to examine how novice and experienced designers approach the design process in the aerospace industry and how this transition from the former to the latter takes place. One of the problems in identifying a multitude of solutions is that rules are not well defined but are open to interpretation on every step of the design process (Cross, & Cross, 1998; Goldschmidt, 1997). This issue leads to uncertainty and ambiguity of the tasks. Also, novice and experienced designers use different approaches in their work. Novices tend to perform backwards and apply a deductive approach; experienced designers reason forward and later alternate between those two methods (Ericsson, & Charness, 1997; Waldron, & Waldron, 1996). The difference is not limited to various strategies, but an expert has the ability to hold more data in working memory (Ericsson, & Charness, 1997). The major finding of the Ahmed, Wallace, and Blessing’s study was that novice and experienced designers used different design patterns. Novices (nine months to five years on a job) tend to employ mainly trial and error, which results in a significant number of iterations and takes a longer time to completion. Inexperienced designers rushed to implementation of a design immediately after its generation and evaluated it afterwards.

Experienced designers (eight to 32 years in industry) evaluated a design before it was implemented with the final evaluation taking place after the design's implementation. This method did reduce the number of design cycles and, in the end, saved engineering time. These were not the only issues the researchers found. Novices and experienced designers used different design strategies to achieve the desired result. The latter group referred most often to previous designs they had worked on, which was one of the most important discoveries in the study.

Based on those findings, it is possible to identify a parallel to engineering and engineering technology students, who fall into the novice category. The fact that only 16 weeks are given for completing the design course makes the task even harder on the students. First of all, they don't have enough experience with the design process and don't understand all the requirements and available options. Secondly, students are stressed to provide a workable design and implement it in the same amount of time without some needed iterations to sort out ambiguity of the process. Basically, their design must work on the first run. In this case, it might be beneficial to offer multi-semester capstone design course versus a single-semester class. The students must be provided time to iterate their design and to build expertise in the process. This should give an opportunity to the students to make a smooth transition to an expert.

Many researchers agree that ambiguity of the design process is amplified and caused by potential miscommunication on different levels between all parties involved in the process. For example, Eckert (1997, 1999, 2001) studied the knitwear design process between 1992 and 1998 to discover a major bottleneck of this process, which she thought was miscommunication between designers and technicians. Similar scenarios exist when engineering technology students are working with engineering students or industry representatives. During Eckert's studies, she visited a number of knitwear companies in Italy, Germany, and Britain, and talked to more than 80 professionals involved in the process. The researcher found that the biggest problem was that technicians have different knowledge and skills than designers and this alone led to misunderstanding the information designers want to convey. This particular study looked at sketches, gestures, and computer supported data.

The reason for this miscommunication is rooted in the ambiguous nature of design. Designers and technicians have different definitions of design. To make the issue more complex, even the word ambiguity has multiple meanings. According to Merriam-Webster (n. d.), it could mean "a: the quality or state of being ambiguous especially in meaning; b: a word or expression that can be understood in two or more possible ways: an ambiguous word or expression." One can't ignore the first aspect of ambiguity, yet Stacey and Eckert (2003) concentrated on the second concept, which is the existence of a multitude of interpretations of ideas in the design process. The authors viewed ambiguity as a beneficial component of the process because it promotes creativity by allowing reinterpretations, such as sketches and computer modeling. Schön (1983) looked at those as conversations because designers always see more information in sketches than they put down on paper. This also could and does lead to ideas generated under certain limitations and design constraints (Finke, 1990). In the Aeronautical Engineering Technology (AET) program at Purdue University, students are tasked to come up with at least three different concepts of their technical solutions to fulfill a need. Those sketches must be generated by the whole team, which is required to use a brainstorming session with all ideas recorded in a design book. Students are allowed to use 3D CATIA software, but it is not mandatory to do so (Dubikovsky & Kestin, 2012).

Based on the above mentioned Stacey and Eckert (2003) study, Cardella and Lande (2007) examined the relationship between ambiguity and design thinking and mathematical thinking. They also looked at sources of ambiguity and engineers' reactions to uncertainty. The researchers found that their subjects tried to reduce ambiguity instead of preserving it. For example, in one instance the group looked at certain solutions after receiving the additional rules for brainstorming in place of generating new ideas. Some reduction of ambiguity was done through application of mathematical thinking, the most common of which was estimation of certain factors, values, requirements, and constraints in numerical form. This became sort of a bridge between both forms of thinking. However, previous studies indicate that engineering students are not skilled enough in estimation (Dym, 2006).

The other useful component of ambiguity is the social nature of design. Designers rarely work alone; most of their time is spent in groups, discussing and brainstorming ideas, concepts, and details of projects. The organizational culture, roles and duties of designers, and interrelations between professionals bring certain influences to those group activities, but don't change the social aspect of the design process (Bucciarelli, 1988, 1994; Henderson, 1999; Minneman, 1991). Minneman (1991) also argues that most of those interactions are negotiations to achieve mutual understanding, not necessarily bring disclosure on an idea. This is very similar to the way AET students work on their projects in teams of three to five members.

Ambiguity requires coping strategies to deal with it. Those mechanisms include the use of gestures, sketches, and speech to reduce or maintain uncertainty (Tang, 1989, 1991; Tang and Leifer, 1988). The researchers found that a process of creating sketches and other representations is equally as important as the representations themselves. The same conclusion was reached by Neilson and Lee (1994) who studied how architects and their clients come to an understanding during kitchen layout projects. Most misunderstandings arose because there was no clear relationship between expressed words and graphical interpretations. Both sides must possess previous knowledge and experience to interpret information correctly. It is highly possible that a designer and a client operate from different object worlds (Bucciarelli, 1988, 1994). Sometimes that is what happens between designers and technicians, as well as engineering professors and engineering technology students.

In conclusion, it is safe to state that ambiguity and design have more than a simple, straightforward relationship. Design is a creative process, which does not have a single correct answer. Contrarily, there are a multitude of solutions to fulfill the design. This alone is a main source of ambiguity. In addition, according to Dym (2006) designers must deal with incomplete information and imperfect modeling. Bucciarelli (1996) adds that different skill levels and professional backgrounds lead to variance in understanding of sketches and other representations. All together this creates a situation open to misinterpretation. Epistemic cognitive development, intellectual growth, design and mathematical thinking, cultural background, teamwork, communication and miscommunication, and many other issues make this connection extremely ambiguous and constitute an interesting topic for further research in general and in the field of engineering education in particular. Addressing those complex matters in instructional curricula is a challenge many programs are facing. One of first possible steps in this development would be an in-depth study of students' tolerance for ambiguity, reduction of social anxiety, and fear of negative evaluation and their connection to the capstone design courses. Also, communication is a vehicle to reduce, ideally to remove, ambiguity from the design process through sketches, computer representations or/and by face-to-face meetings and conversations. All of those ways to communicate, plus other means like Dropbox, Google Documents, and email, for example, are employed by the research subjects to relay information to their engineering counterparts. It is also noted that ambiguity is not necessarily a negative issue. It does have certain benefits like allowing creativity to flourish. As a result, alternative solutions emerge, which can improve the product. Adjusting project requirements and proposed solutions through negotiation is a major part of every design process. Communicating ideas is a crucial part of the process and it also helps to clarify misunderstandings. Maher and Simoff (2000) discovered that 20 percent of all communications between designers take place to make sure all parties involved are "on the same page." This alone reduces cost and time wasted. In sum, "ambiguity is essential to the design process, allowing participants the freedom to maneuver independently within object worlds and providing room for the recasting of meaning in the negotiations with others." (Bucciarelli, 1994, p. 178).

## 2.5 Research on Tolerance for Ambiguity

There has been a great deal of research on tolerance for ambiguity that discusses the complexity of the topic. Despite the fact that there have been years of studies by psychologists, management experts, and educators, the field of ambiguity and its role in education is mostly still unknown and not well understood (Atkinson, 1984; *Fox, 1957;* Katz, 1984; Simpson, Dalgaard, & O'Brien, 1986). However, by conducting the past studies, studying and analyzing results, a solid theoretical foundation has been laid for future research projects and discoveries.

To begin the discussion about tolerance for ambiguity, refer to Furnham and Ribchester (1995), who defined tolerance for ambiguity as the way a person (or a group of people) perceives and processes unfamiliar, partial, or overly complex information in ambiguous or uncertain situations. In such conditions, people with a low tolerance for ambiguity experience anxiety and become stressed. In contrast, individuals with a high tolerance for ambiguity perceive these same situations as a challenge and are able to see the changes in a more interesting light that allows for a wider range of responses.

Over the years, a multitude of studies were performed and many variables, such as personality, age, ethnicity, and gender, were identified and analyzed. The main goal of such studies was to determine if any of these variables could be used to predict a person’s tolerance for ambiguity. For example, Tatzel (1980) studied college students who were undergoing changes in life situations. He discovered that individuals in their late 20’s were less tolerant of ambiguity in comparison to younger people. Moreover, he found that art students had more tolerance for ambiguity than those students who were studying business. In another study, Rotter and O'Connell (1982) determined that tolerance for ambiguity was inversely related to cognitive complexity.

According to Foxman (1976), a tolerance for ambiguity is an adaptive cognitive behavior that functions to help people cope with unstructured stimuli. At the same time, tolerance for ambiguity takes a key role in self-actualization and molds changes in character. Self-actualization is defined as an individual's desire to understand their potential and to perform on that potential. As a result, Foxman offered up the hypothesis that people with higher self-actualization perform better on tolerance for ambiguity tests. In order to measure self-actualization, he selected the Tennessee Self Concept Scale (TSCS) and administered the test to 33 students randomly chosen from a pool of 77. After the conclusion of the preliminary step and further selection, 18 people with the highest and lowest scores were given the Rorschach inkblot ambiguous test. At the end of the study, the researcher found that the individuals with the higher scores of self-actualization were also the ones with the higher scores of tolerance for ambiguity. Another finding was that gender did not play any role in performance during the tests and did not affect the correlation between those two factors. Foxman concluded that tolerance for ambiguity is positively correlated to self-actualization, and that tolerance for ambiguity could be utilized as a predictor for potential mental health status and future formation of personality.

A study administered by Ashford and Cummings (1985) linked tolerance for ambiguity to feedback-seeking behavior. Bennett, Herold, and Ashford (1990) returned to this study and reinterpreted it again to address some problematic assumptions, which were made in the original research. The original study consisted of a group of 172 employees of a

Midwest utility company. These individuals answered a questionnaire which measured two behaviors: one aspect of the questionnaire was related to tolerance for ambiguity in job-related activities and another measure addressed tolerance for ambiguity in situations that required problem-solving.

In the newer version of the study, the two sets of data were analyzed separately in contrast to the original study, which did not distinguish between those areas. Separation of the two categories greatly improved the results. The goal of the study was to discover if there was a connection between the levels of tolerance for ambiguity and engagement in feedback-seeking behavior. In other words, is it true that employees with lower tolerance for ambiguity use feedback as a tool in uncertain situations?

From the data analysis it became apparent that job-related tolerance for ambiguity reinforced feedback seeking behavior: in uncertain situations, someone with low tolerance for ambiguity constantly seeks out feedback to justify his or her decisions. Bennett et al (1990) concluded that tolerance for ambiguity determines the decisions of an individual based on how much feedback he or she requires at work. That conclusion could potentially shape a management style in uncertain situations. In some cases, managers must spend more time and provide more feedback to employees with lower tolerance for ambiguity, which might be necessary in the modern workplace, as Bennett et al put it, “organizational reality.”

This topic of uncertainty attracts many management, economist, and business researchers. Another example of this was the study of 412 mid-level bank managers in Greece performed by Katsaros and Nicolaidis (2012). The goal of the study was to examine if a manager’s ambiguity tolerance could be influenced by his or her attitude, personal traits, and emotions. The researchers wanted to test six different hypotheses, including if locus of control significantly affects ambiguity tolerance; if a higher tolerance for ambiguity indicates higher job satisfaction, more positive emotions, as well as increased organizational commitment. Katsaros et al also investigated if high tolerance for ambiguity improved interest and if the variables of emotions, attitudes, traits, and demographical characteristics affected ambiguity tolerance. The analysis produced mixed results.

The researchers found strong evidence that locus of control and interactions of traits and emotions did positively affect ambiguity tolerance. The relationship between tolerance for ambiguity and increased importance and interest was positive but weak. Further, it was found that ambiguity tolerance and organizational commitment had a negative correlation. All other hypotheses were not statistically significant. Overall, the results showed that the study participants in general had a low tolerance of ambiguity, which was in line with a previous study performed in 2001. According to Hofstede (2001), out of 56 nations, Greece showed the highest uncertainty avoidance level.

Given the importance and interest in promoting economy growth, some researchers asked another question: *What is the difference between managers and entrepreneurs? Why and how are certain people taking a risk to start their own businesses?* Schere (1982) compared entrepreneurs, budding entrepreneurs (defined as potential entrepreneur candidates), and mid-level managers and executives. His theory was that the first group (entrepreneurs and potential entrepreneurs) had higher tolerance for ambiguity than the latter one (mid-level managers and executives). The researcher could potentially look at two factors in his study: personal psychological traits or an environment in which individuals did not have control. He chose the first factor.

The selected individuals were asked to fill out Budner's (1962) survey, which was later analyzed. The results revealed that entrepreneurs exhibited the highest tolerance for ambiguity, followed by budding entrepreneurs. Executives and managers showed the lowest level of tolerance for ambiguity. The findings were very much in line with the pre-study's hypothesis. Schere did not stop there but continued his study comparing top-level executives versus mid-level managers as well as a comparison between entrepreneurs and entrepreneur candidates. The results of this sub-study showed that there was a significant difference in ambiguity tolerance between managers and executives, but that no such difference was found between the members of the entrepreneurial group.

There are many examples of research of tolerance for ambiguity in management and business. Some studies have also been done in the medical field. For example, researchers at the Johns Hopkins School of Public Health examined 386 students through the course of their studies at medical school. The students were asked to diagnose and treat alcoholism. The study yielded very interesting results in that tolerance for ambiguity did not change or expand over the four years of medical school in those students. Additionally, it was found that ambiguity tolerance was lower in males and that future psychiatrists were more tolerant compared to surgeons (Geller, Faden, & Levine, 1990). However, limited examples of research on tolerance for ambiguity in engineering or engineering education fields were found. Keywords such as *ambiguity, uncertainty, engineering, technology, engineering education, engineering design, design process, mechanical design*, and various combinations of those words were used in different databases with limited success. Although it is worth noting a study done by Koretsky, Kelly, and Gummer in 2011, which looked at changes in students' perceptions of the nature of ambiguity in both physical and virtual laboratory environments. The researchers concluded that students' perceptions of ambiguity transferred from the instructional ambiguity to an ambiguity in the process of the experiment itself. Still, there is a wide-open field to conduct research in tolerance for ambiguity related to engineering, engineering education, or engineering design. This study has a goal to narrow the gap of knowledge on this topic in the given field.

## 2.6 Tolerance for Ambiguity Instruments

One of the challenges in the study of tolerance for ambiguity has been how to assess this ability. The quest to create a valid instrument started in the 1920s. In 1949, Frenkel-Brunswik (1949) defined intolerance for ambiguity as an "emotional and perceptual personality variable" (p. 108) and offered first cognitive test called "The Dog-Cat Test." An image of a dog was shown to test participants initially, followed by series of 12 additional pictures during which the dog was gradually transferred into a cat. Individuals, who did not accept this transformation for the longest time, were considered to have the lowest tolerance of ambiguity (Frenkel-Brunswik, 1949). However, this test was limited in that it ignored strong intelligence-tolerance of ambiguity relationships (Furnham & Ribchester, 1995).

There were at least five well-regarded surveys developed to deploy quantitative methods measuring this ability: Walk's A Scale (O'Connor, 1952), Budner's scale (Budner, 1962), Rydell's scale (Rydell & Rosen, 1966), MacDonald (1970), and Norton (1975). Budner (1962) described tolerance for ambiguity as "the tendency to perceive ambiguous situations as desirable" (p. 29) and introduced a 16-question test covering three types of ambiguous sceneries: novel, complex, and insoluble. Rydell and Rosen (1966) developed the Ambiguity Tolerance-16 scale (AT-16) consisting of 16 false-true questions, however, it did not display evidence of internal reliability (Furnham & Ribchester, 1995). In 1970, MacDonald performed psychometric evaluations and added four new questions to improve the Rydell-Rosen test.

To develop an effective and valid test, Norton (1975) analyzed content of all papers from 1933 to 1970 in the Psychology Abstracts related to or containing the word ambiguity. He identified eight themes in definition of the word: (1) multiple meanings, (2) vagueness, incompleteness, fragmented, (3) as a probability, (4) unstructured, (5) lack of information, (6) uncertainty, (7) inconsistencies, contradictions, contraries, and (8) unclear. Norton also compared five valid and well established tools: Meresko, Rubin, Shontz, and Marrow's test (Rigidity of Attitudes Regarding Personal Habits), Troldahl and Powell's Short Dogmatism Scale; Martin and Westie's Intolerance of Ambiguity scale; Budner's Intolerance of Ambiguity test, and Rehfisch's Rigidity measure (Norton, 1975). The Norton test was evaluated and deemed to have a valid construct.

## 2.7 Fear of Negative Evaluation and an Instrument to Measure It

According to the American Psychiatric Association (APA) (1994), social anxiety in general is a condition containing "marked and persistent fear of one or more social or performance situations in which the person is exposed to unfamiliar people or to possible scrutiny by others (p. 416)." The definition of more specific to this study social-evaluative anxiety is given by Watson and Friend (1969, p. 448):

> "Social-evaluative anxiety was initially defined as the experience of distress, discomfort, fear, anxiety, etc., in social situations; as the deliberate avoidance of social situations; and finally as a fear of receiving negative evaluations from others."

Social anxiety impacts all aspects of individuals' lives: at home, at school, and at work (Higa & Daleiden, 2008; Wittchen, Stein, & Kesler, 1999). It is characterized by strong fear of negative evaluation, which leads to the perception of ambiguous situations as a danger (Dadds, Barrett, Rapee, & Ryan, 1996). In other cases, if possible, individuals try to avoid any situation where their performance can be evaluated or that could be potentially socially embarrassing (Beidel, & Morris, 1995; Beidel, Christ, & Long, 1991; Beidel & Turner, 1998). During capstone courses those situations cannot be completely eliminated, because students must work as a team and are evaluated by their peers throughout a project. Plus, progress reports and final products must be offered to the whole class and sometimes external stakeholders in a face-to-face presentation. Each student has her or his own project section to report, which is linked to social performance. There is a strong evidence that socially anxious individuals demonstrate profound negative interpretation biases of their social performance (Amir, Beard, & Bower, 2005; Brendle & Wenzel, 2004; Voncken, Bogels, & de Vries, 2003; Wenzel, Finstrom, Jordan, & Brendle, 2005). Those individuals cannot objectively evaluate their own social performance and always look for faults in it (Mellings, & Alden, 2000; Rapee, & Lim, 1992; Stopa, & Clark, 1993). It is important to note that, according to many recent studies, this happens not because individuals are lacking sufficient social skills, but because they *believe* they are (Clark & Wells, 1995; Rapee & Heimberg, 1997; Rapee & Lim, 1992; Strahan & Conger, 1998). The subsequent lower level of confidence (Lundh & Sperling, 2002; Stopa & Clark, 1993), reduced self-esteem (Kocovski & Endler, 2000), and fear of negative evaluation (Izgiç, Akyüz, Doğan, & Kuğu, 2004; Rapee & Lim, 1992; Rodebaugh & Chambless, 2002) are associated with those beliefs. Further studies proved that cognitive interventions can and do modify those issues (Wells, & Papageorgiou, 2001).

The current study focuses on the possible relationship between the ambiguous nature of engineering projects in capstone courses and fear of negative evaluation. A definition of fear of negative evaluation, according to Watson and Friend (1969, p. 449), is:

> "…defined as apprehension about others' evaluations, distress over their negative evaluations, avoidance of evaluative situations, and the expectation that others would evaluate oneself negatively."

Based on research completed by Jackson (1969), Watson and Friend (1969) developed a test to measure social anxiety. The test consisted of two independently employed sub-tests: Social Avoidance and Distress (28 items scored *true* and *false*), and Fear of Negative Evaluation (30 items scored *true* and *false*) scales. The latter survey instrument, which became the most used instrument in measuring social phobia and social anxiety research (Leary, 1983; Orsillo, 2001), was utilized in the current study. The Fear of Negative Evaluation scale has proven to be highly reliable and able to predict a multitude of aspects of social anxiety (Friend & Gilbert, 1973; Smith & Sarason, 1975; Watson & Friend, 1969).

## 2.8 Instructional Design Framework

Active learning, a selection of special methods where learners under the guidance of an instructor are responsible for their own learning, is not a new concept. Almost a hundred years ago, Charles Riborg Mann (1918) in his "A Study of Engineering Education" proposed a similar idea. In the last thirty years, active learning has gained momentum in many areas of teaching engineering science. In short, it is up to the students to create an individual list of topics that they want to explore and learn. In such a setting, an instructor is not acting as a presenter of knowledge, but instead serves as a facilitator or a guide for the students to reach their goals (Maudsley, 1999).

The same concept was introduced by Dewey (1938), who believed that effective learning happens through experience. According to Dewey, learning is socially constructed and requires different freedoms, be it freedom of judgment or freedom of thought. In other words, Dewey connected education with real life and the presence of society.

Additionally, he also emphasized collaboration as **a** tool to bring another dimension to understanding. By working in groups, students are exposed to alternative ideas, which function to widen learners' view of a topic and the world in which it functions.

Another theorist, Bruner, strongly opposed memorization of facts in the classroom. He promoted an active learning approach where a teacher brings structure to a course but does not just transfer his or her own knowledge through lectures. This would be done with the belief that students should be genuinely interested in new ideas and that this would spur the learning experience. The role of an instructor in such a school setting is to encourage a center of facilitated learning and to find new, innovative teaching methods that are tailored to the students (Bruner, 1968).

Over the last 30 years, the active learning approach has received wide recognition and application in various programs throughout the US and abroad (Pomberger, 1993; Thorpe, 1984). Students, working in teams, are required to solve an ill-structured problem with no single, identifiable solution (Woods, 1994). For example, this approach was used in a curriculum at Massachusetts Institute of Technology in its Aeronautics and Astronautics program. Throughout their four years of study, students were to find solutions for different projects in many courses, starting with their freshman year and continuing through graduation. These future engineers designed, built, and tested radio-controlled lighter-than-air (LTA) aircraft, and worked on complex space systems (Brodeur, Young, & Blair, 2002). At Purdue University, students from the Department of Aviation technology work on numerous projects, starting with identifying a problem, specifying its requirements, planning its progress, and manufacturing a final product (Dubikovsky, Ropp, & Lesczynski, 2010). North Dakota State University's Department of Civil Engineering and Construction also uses problem-based learning courses in its curriculum (McIntyre, 2003).

During those and many more courses, traditional lectures are replaced by open-ended problems, where the students themselves are required to identify a problem and to subsequently solve it over a given period of time. Since the students are allowed to choose the topics, it is the instructor's role to be a guide or facilitator in this unfamiliar process (Dewey, 1938; Kilpatrick, 1918, 1921; Maudsley, 1999). The students actively and constantly engage in self-reflection during problem solving in order to promote higher-order thinking (Hmelo, & Ferrari, 1997).

The main goal of active learning is to prepare students for future employment in industry. Another aim is to create opportunities for students to apply knowledge instead of simply acquiring it in the classroom setting. Problem-based learning concentrates on problem definition as well as problem-solving ability. Real-world engineering tasks and projects are then the best media to learn and develop these skills as opposed to the currently offered detached-from-reality “engineering” senior design problems (Jonassen, Strobel, & Lee, 2006).

In the ideal learning environment, students would be required to contact stakeholders, research the market, and come up with functional design requirements. Moreover, it would be in the students’ best interests if they were required to use industry accepted standards, processes, and procedures, including establishing timelines and gate reviews’ deadlines, budget limitations, drawing generation, production of components and parts, and assembling a final product. In this case, students would greatly benefit from their own participation in the project (Massa, 2008). All of these activities will potentially help to extend the ability to tolerate ambiguity better, which is the goal of this research.

## 2.9 Engineering Technology Curricula

As one could imagine, the engineer must deal with many philosophical uncertainties listed above. In addition to those, there are many other more practical aspects the engineer must address, such as finding and keeping employment, keeping up with ever-changing technology, and maintaining professional growth. The engineer must be able to wear "many hats." The current study's main concern is about current engineering and engineering technology curricula and that many of those challenges are ignored or minimally addressed in most universities and colleges. Engineering and engineering technology students are tasked to solve mathematical problems, learn drafting and modeling skills. Expertise in those areas is important for future engineers, however, it does not prepare the students for challenges they will face in their day-to-day professional life. One of the "bright spots" in the curricula for technology programs, for example, is that ABET requires those programs to "prepare graduates with knowledge, problem-solving ability, and hands-on skills to enter careers in the design, installation, manufacturing, testing, evaluation, technical sales, or maintenance of aeronautical/aerospace systems" (ABET, 2015b, p. 5). Other programs seeking the ABET accreditation must fulfill similar requirements. In practical terms, this criterion leads to offering senior capstone design courses, which is a big step in introducing students to some of the future engineering everyday problems and to help the students develop strategies to cope with ambiguity and uncertainty.

Most senior capstone design classes use elements of active learning, which allows students to become the driving force of their own learning. Traditional lectures are replaced by open-ended projects, which are perceived by learners as important and meaningful. The students choose topics they want to learn under the guidance of an instructor (Maudsley, 1999). To promote higher-order thinking, the students actively participate in self-reflection during a project (Hmelo, & Ferrari, 1997). By going through "real-life" problem-solving, which is better than many detached "academic only" problems, students are getting ready for employment in industry (Jonassen, Strobel, & Lee, 2006).

However, a danger exists in allowing too little or no guidance to the students in problem-based, discovery, experimental, and inquiry-based learning (Kirschner, Sweller, & Clark, 2006). According to these researchers, the main problem is that sometimes intricate relationships between long-term and working memories are ignored in human cognitive architecture. That potentially could lead to an ineffectiveness of any form of active learning. Learners must alter their long-term memory through working memory. No learning takes place if there is no change happening to long-term memory, retrieval, or storage of information. One needs to keep in mind that the human memory is unable to process an overly large amount of information. For example, the brain can process two to three items at a time and in no more than in thirty seconds. These conditions limit learning of new information. The working memory could be easily overwhelmed by an increasing amount of information during problem- or other based learning courses. This could be a potential problem for an active learning approach, if these facts are ignored. All the factors mentioned above dictate careful and thoughtful selection and implementation of learning activities during any form of active learning to make learning successful.

Realizing this information, there are reasonable concerns about the implementation of senior capstone design courses. The students should not just be “cut loose,” trying to make sense of all required steps, starting with defining a problem, specifying design requirements, dealing with stakeholders, and many other complicated engineering tasks. An instructor must also resist the desires of universities and colleges to increase a teaching load and the number of learners in a classroom. Both of these tendencies, in the current researcher's opinion, negatively influence the quality of a teacher's mentoring and guidance abilities.

To cope with uncertainty and ambiguity during the senior capstone design courses, an instructor must introduce the students to many methodologies used in the industry, for example, Information-Gap Decision Theory (IGDT), an approach assisting decision making in uncertain situations, which determines if a "good enough" alternative of a given design could be more robust (Ben-Haim, 2001). Another useful tool is the Six Sigma methodology and project management instruments widely employed in industry. The author of the current study successfully introduced this particular approach in his senior capstone design courses (Dubikovsky & Kestin, 2012). All of the tools mentioned above and many others helped to reduce uncertainty and ambiguity by applying a systematic and logical approach, to slice a big problem into smaller, better managed pieces.

An opportunity for students to actually work on a real product, process, or/and service under the guidance of an experienced instructor, provides first-hand experience on how to reduce both ambiguity and uncertainty and how to use many available tools when dealing with those topics. Future engineers should hear and relate to a quote of the famous engineer Theodore Von Karman that both Koen (2003) and Bucciarelli (2003) used in their papers: "Scientists discover the world that exists; engineers create the world that never was."

## 2.10 Misconceptions

The most important role of an instructor is to address the many misconceptions about the design process and project management the students may have. For example, many learners do not realize that the conceptual design phase takes time, and requires a deep and solid understanding of a task (Pahl, & Beitz, 1996). One of the most common misconceptions is that a well-done, detailed design could balance out the shortcomings of a selected and approved concept (Pahl, & Beitz, 1996). Another group of misconceptions is connected to the project management area; many students have the idea that management teams would lead them as engineers in step-by-step fashion and all that students should know is how to follow instructions (Rugirok, Peck, Fenton, & Conyon, 1999; Turner, 1999; Whittington, 1999). There is also a misconception that engineers are given unlimited resources, time and funds, to achieve the final design (Payne, 1995).

## 2.11 Summary

As it was stated earlier, many studies have not specifically target engineering, engineering technology, and engineering/engineering technology education. However, most studies mentioned operated with unfamiliar, partial and complex information in unrestricted situations. Those attributes are clearly present in the design process, where engineers must deal with insufficient information and provide “the best” possible solution (Koen, 2003).

Another topic mentioned in the literature is cognitive complexity, which is also connected to the design process and functions performed by engineers. Feedback-seeking behavior is another attribute of design: on one hand, it is required by individuals with lower tolerance for ambiguity; on the other hand, the feedback is needed to make sure the design is still “on track” and is fulfilling a certain need and/or want of the customer. That issue shapes management style used in engineering departments and companies. It is also affects specific areas of engineering professions, such as field, test, liaison, and other forms of engineering.

To sum up, the literature review show that even though some research on tolerance for ambiguity was done over the course of many years, the areas of engineering, engineering education, and engineering design are still largely unexplored in this regard. However, many attributes explored in earlier studies are equally important for engineers as they are for medical personnel and managers. It was also discovered that tolerance for ambiguity is an important ability for an engineer; this includes the ability to encounter, evaluate, and successfully cope with the discomfort of unknown situations or situations with insufficient information.

Based on the literature, it is possible to manage, keep the same, and even possibly improve, this ability by offering senior capstone design classes that utilize an active, and more specifically problem-based, learning approach. By examining a body of knowledge related to tolerance and intolerance for ambiguity, it is possible to identify and select an appropriate, sufficient, and easy to use instrument for this purpose. The goal of the current study is to examine students’ perceptions on their capstone design experiences and to record effects of previous exposure to ambiguity.

# CHAPTER 3. METHODS

## 3.1 Methodological and Theoretical Framework

One of the most established scientific methods is a quantitative approach, where a survey and/or other instruments are used to collect data/responses from a large pool of participants. Johnson and Onwuegbuzie (2004) listed advantages and disadvantages of this approach: "The major characteristics of traditional *quantitative* research are a focus on deduction, confirmation, theory/hypothesis testing, explanation, prediction, standardized data collection, and statistical analysis" (p. 18). Since the current study has a hypothesis that can be tested, that a relationship between fear of negative evaluation and tolerance for ambiguity exists, a quantitative approach was used for the current study. The statistical method applied was multiple regression, where fear of negative evaluation is a predictor and tolerance for ambiguity is an outcome. To understand the relationship better, exposure to ambiguity prior to a capstone course served as a moderator for this relationship.

A moderator is a variable that increases or decreases intensity of the relation between a predictor and an outcome (Baron & Kenny, 1986; Holmbeck, 1997; James & Brett, 1984). A moderator effect is an interaction itself, which can and does alter one variable based on the strength of another. Strong relationships are the best application to discover moderator effects (Chaplin, 1991; Jaccard, Turrisi, & Wan, 1990). Use of moderators is widely used in social science and reflects depth of the field (Aguinis, Boik, & Pierce, 2001; Cohen & Cohen, 1975; Cohen, Cohen, West, & Aiken, 2003; Judd, McClelland, & Culhane, 1995).

As in all quantitative studies, a larger number of research participants is desirable to increase statistical power (Cohen, 1990; Cohen, 1992). However, it is not always practical or even possible to do so. If the number of predictors is greater than one, the recommended number of participants is equal or greater than 50 + 8 x number of independent variables as suggested by Green (1991). This procedure is similar to a recommendation by Harris (1985), who suggests using the number of predictor variables plus 50. Other sources recommend 10 responses per predictor variable, if six or more predictors are used for regression (VanVoorhis & Morgan, 2007). To make sure that the results are not established by chance, the likelihood of a false positive result should be equal to or less than 0.05 (Aron & Aron, 1999).

## 3.2 Research Questions

- What is the association between tolerance for ambiguity and fear of negative evaluation at the beginning and the end of engineering technology capstone courses?
- How does exposure to ambiguity prior to capstone courses and during them affect tolerance for ambiguity?

## 3.3 Research Hypotheses

- Tolerance for ambiguity will increase after completion of a capstone course.
- Fear of negative evaluation will decrease after completion of a capstone course.
- Earlier exposure to ambiguity in a curriculum will decrease fear of negative evaluation during a capstone course.
- Earlier exposure to ambiguity in a curriculum will increase tolerance for ambiguity during a capstone course.
- Fear of negative evaluation will be negatively related to tolerance for ambiguity.

## 3.4 Research Design

To answer the first of research questions, autoregressive cross-lagged model was utilized as the best fit. It is a statistical method for predicting the change in the dependent variable (in the case of the current study, post-project Tolerance for Ambiguity) due to the change in multiple independent variables (pre-project Tolerance for Ambiguity, Pre- and post-project Fear of Negative Evaluation, instructor effect, and Exposure to Ambiguity prior to the project). The model also allowed examining moderation or if the relation between the final Tolerance for Ambiguity and the final Fear of Negative Evaluation depends on Exposure to Ambiguity prior to the project (Bollen & Curran, 2006). To examine the second research question, correlations were employed because it is the best statistical method to test association or lack of the relationship between Tolerance for Ambiguity and Fear of Negative Evaluation (Aiken & West, 1991).

In total, three survey instruments were used for the current study. Two of them collected data on subjects' tolerance for ambiguity and fear of negative evaluation at the beginning and the end of the project. Both instruments were previously developed, validated, and widely used in the field of psychology. The first one, the Fear of Negative Evaluation scale, has proven to be highly reliable and able to predict a multitude of aspects of social anxiety (see Appendix A for full version of the survey) (Friend & Gilbert, 1973; Smith & Sarason, 1975; Watson & Friend, 1969). The second one, the MacDonald survey, was chosen because it was relatively short, reliable, and multidimensional (see Appendix B for full version of the survey). MacDonald's survey selection was also based on work by Furnham (1994), who examined Walk's A Scale (O'Connor, 1952), Budner's scale (Budner, 1962), Rydell's scale (Rydell & Rosen, 1966), MacDonald (1970), and Norton (1975). The third newly developed survey instrument took place in the middle of the experience to measure students' exposure to ambiguity prior to the capstone course. The latter instrument was developed during the current study. It is based on Furnham's (1994) emerged six factors: (1) *problem-solving* (most important), (2) *anxiety*, (3) desire to *complete* a problem, (4) *adventurousness*, (5) *uncertainty seeking,* and (6) *problem fragmentation* (least important). The purpose of the survey is to measure students' exposure to ambiguity, establishing levels of exposure to ambiguous situations and projects prior to a capstone course, during first three years in a curriculum and before enrolment in college. More information on the instrument will be provided later in this section. The responses to these questions were used to determine if exposure to ambiguity moderates the relationship between fear of negative evaluation and tolerance for ambiguity in the end of projects, and if so, how those interactions qualify any main effects. Controlling for instructors was added to the second phase of the study as an additional predictor, but the effect of difference in the instructors was not in the scope of the original study. Grades earned by the students in the courses were not taken into the current study, because of difficulty associated with problem- and project-based team-based learning (Kilpatrick, 1921). The research design is represented in Figure 3.1. Because of the size of the population in a single capstone course, multiple groups of students from different courses were combined to draw conclusions. This aggregation was possible because the very nature of engineering work, as it was discussed before, includes a high level of ambiguity in each and every project, regardless of school, department, or program. The capstone courses studied were limited to engineering technology programs only, where the process of ABET accreditation helps to ensure similarity because the programs must fulfill similar requirements. The programs in this study have different industry specific curricular focuses and carriers, but they all must be evaluated and accredited by the same commission and concentrate on practical application and employment (ABET, 2015b).

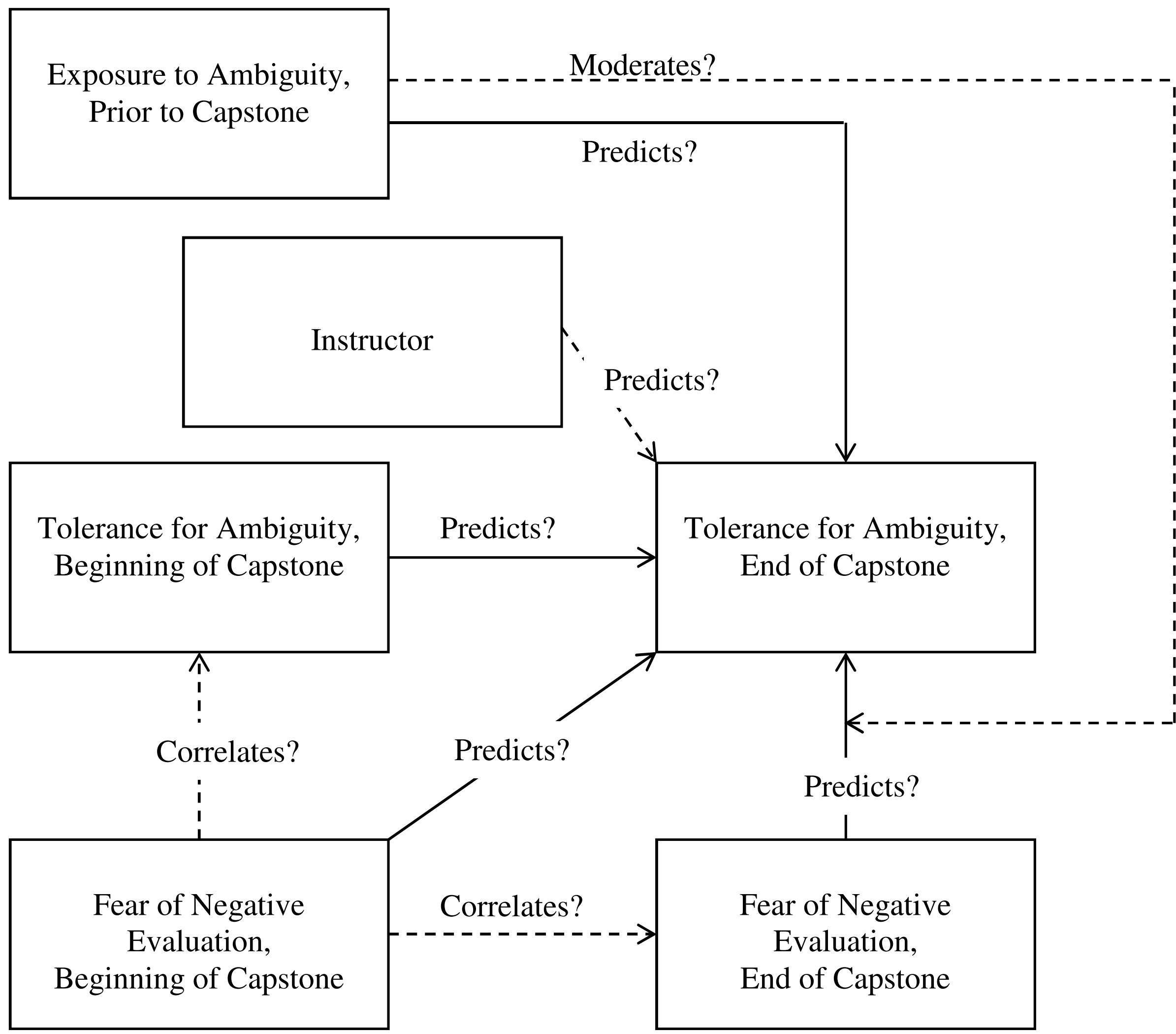


Figure 3.1: Relationship between Tolerance for Ambiguity, Fear of Negative Evaluation, Instructors, and Historical Exposure to Ambiguity instruments

## 3.5 Research Site

The primary research was the Purdue Polytechnic Institute (PPI). The PPI, formerly known as the College of Technology, is in the process undergoing a major transformation for all its programs. It will be an institution where theory-based learning merges with applied engineering and industry-sponsored senior capstone projects in the team environment. The deadline to implement all new curricula will be August of 2017. Students' learning in technical disciplines is supplemented with humanities studies. Competency-based outcomes ensure that students are ready for the global workplace. Such activities as certification opportunities, internships, and international immersions help the students to be successful after graduation. The PPI was also chosen because capstone projects in technology programs are, in general, more hands-on than in many engineering programs. Most of the courses in PPI require tangible final deliverables, which could be finished final assemblies or prototypes. While some technology programs accept final reports to meet the requirements of the capstone project, all participants in this study will have been engaged in designing and creating a tangible artifact.

## 3.6 Course Selection Criteria

In the current study, courses were identified that would be able to examine participations' perceptions in a senior design project, their ability to tolerate ambiguity, and how anxiety becomes a major factor in this experience. The primary study courses were selected from newly renamed Purdue Polytechnic Institute (PPI), formerly Purdue University's College of Technology. The PPI currently is going through transformation from structured and lecture-based learning to a more desirable active learning model. This transformation allows for better reflect on a changing workplace and the mission of the institution. At that time, many common initiatives were implemented across the PPI, including common criteria for senior capstone courses: "Team-based, learn-by-doing activities will be formally integrated throughout the Polytechnic Institute curriculum from freshman year through industry-sponsored, senior capstone projects and internship experiences. When we combine these with an integration with humanities, students will build their understanding of the complex nature of applying technology to social issues, problems and solutions at varying scales" (Purdue University, May 15, 2015). This idea is even better described in the PPI's Polymeter, which is the document addressing all curricula changes requirements:

> "Capstone Experience: Every program should have a capstone experience in which students work on real-world problems of significance that require a synthesis of disciplinary knowledge acquired through their plan of study. While each department may implement this in varying ways, the ideal capstone experience would be a year-long, industry driven project that could be individual or group-based (depending on discipline, type and scope of the project). Creativity and innovation in problem solving should be evident in the solutions, processes and products developed and implemented by students in these capstone experiences" (PPI, 2015, p. 5).

According to the Polymeter, by the fall of 2016 all capstone courses must be offered in two consecutive semesters, which provides a yearlong experience to students. Most PPI schools and departments already follow this structure. For example, the capstone course in Aeronautical Engineering Technology program is structured as a mock "independent business", such as a research, design and engineering enterprise or firm (Debelak, & Roth, 1982; Howerton, 1988). Students must be "hired" to perform specific tasks according to necessity and their own wishes and abilities (Dubikovsky, 2014). All PPI students must take the pre-requisite courses and should possess knowledge of the discipline-specific critical basics of procedures, logistics, and the reasoning behind them. This particular understanding is crucial for active learning (Shakirova, 2007). Based on this previous knowledge, students would be able to create new instructions, service, or product. During a project, student teams must identify a problem, along with its severity level and importance. The project's purpose, goals, and the scope must be examined and specified by the students themselves. The main goal of this exercise is to find projects that are useful, meaningful, and necessary to conduct technical research or improve learning activities, preferably guided by industry representatives (PPI, 2015). Ideally, "general topic" lectures have been significantly reduced or completely eliminated and replaced by requirements for results that were driven by the projects. There is still need for topic-specific lectures such as project management and industry restricted practices and policies. It might best to involve industry representatives, who have the direct knowledge of the topics. However, students' self-study activities could be another avenue to learn. At the end of the class, students are expected to manufacture parts and assemblies per developed specifications, successfully apply project management tools, and to provide tangible deliverables to their customers and stakeholders.

The engineering capstone course employs and brings together the most complicated and misunderstood components such as design elements and project management (Brown, 2009; Christensen & Rundus, 2003; Eisner, 1997; Hales & Gooch, 2004; Pahl & Beitz, 1996; PMI, 2000; Thomke & Reinersten, 2012). In many cases, capstone is the only place in a program where most of those elements are present in a form of an application of them (Middleton & Burch, 1996; Todd, Magleby, Sorensen, Swan, & Anthony, 1995;

Todd, & Magleby, 2005). The problem-based approach allows students to receive the first-hand project-oriented experience using an application of everything the students learned during their tenure at a college level institution (Callele, & Makaroff, 2006; Lehman, & Belady, 1985; National Research Council, 1991). It integrates the use of formal design methods with additional information and project management tools on how to deal with uncertainty and incomplete information (Courter, Millar, & Lyons, 1998; Dutta, Geister, & Tryggvason, 2004).

## 3.7 Participating Students

The primary students participating in the current study were seniors enrolled in the Purdue Polytechnic Institute who are required to take the capstone design course to graduate (ABET, 2015b). The subjects were mostly 20-22 year-olds with the exception of some older students who came to the programs from industry looking for advancement or changing a field of employment. The number of students in the courses varies from 40 to 140. The students were most likely interested in hands-on, practical application of engineering science. This conclusion was based on the recruitment messages reflected on Purdue University admission website dedicated to the Purdue Polytechnic Institute: "You'll learn side-by-side with professors who have worked in the industry and thrive on combining theory, imagination and real-world application. In this innovative environment, you'll learn by doing - gaining deep technical knowledge and applied skills in your chosen discipline as well as the problem-solving, critical-thinking, communication and leadership skills employers desire" (Purdue University, 2015).

Most programs at the Purdue Polytechnic Institute are accredited by the Technology Accreditation Commission of ABET or in process to get the accreditation. Some programs have unique accreditations required by different fields of expertise. However, many requirements of those accreditation bodies are similar in nature, because the main purpose of any accreditation is to provide "assurance that a college or university program meets the quality standards of the profession for which that program prepares graduates" (ABET, 2015a). This is another reason that all seniors in the Purdue Polytechnic Institute have a common background and are going through similar experiences with ambiguous and uncertain learning activities and projects, as well as dealing with constant evaluation of their work. This applies not just to engineering technology students but also to engineering students from Purdue University and other institutions. Such students are more theory focused, however, the very nature of engineering activities and similarity of programs' accreditations make it possible to combine courses from different departments, schools, and institutions.

## 3.8 Tolerance for Ambiguity Survey Instrument Selection

There are at least five major survey instruments available to measure tolerance for ambiguity: Walk's A Scale (O'Connor, 1952), Budner's scale (Budner, 1962), Rydell's scale (Rydell & Rosen, 1966), MacDonald (1970), and Norton (1975). Which one is the most appropriate for the study? To answer this question, the researcher used findings of Furnham (1994), who combined Rydell and Rosen scale with MacDonald test, compared and analyzed the resulting four tests. The results can be found in Table 3.1.

Table 3.1

*Internal Reliability of the Survey Scales*

*(N=243)*

| | No. of items | Reversed item | Alpha |
|---|---|---|---|
| Norton (1975) | 69 | 7 | 0.89 |
| Walk (O'Connor, 1952) | 8 | 3 | 0.58 |
| Rydell & Rosen (1966) | | | |
| MacDonald (1970) | 20 | 5 | 0.78 |
| Budber (1962) | 16 | 8 | 0.59 |
| | Intercorrelations | | |
| | N | W | R |
| 1. Norton (N) | - | - | - |
| 2. Walk (W) | 0.54 | - | - |
| 3. Rydell & Rosen (R )/MacDonald | 0.82 | 0.62 | - |
| 4. Budner (B) | 0.47 | 0.44 | 0.57 |

*Note*. From "A content, correlational and factor analytic study of four tolerance of ambiguity questionnaires," by A. Furnham, 1994, *Personality and Individual Differences*, 16(3), p. 406. Copyright 1994 by Elsevier Science Ltd.

The MacDonald survey was selected because it was relatively short, reliable, and the most multidimensional. This conclusion was based on work which was done by Furnham (1994), who examined all of the most-used instruments, Walk's A Scale (O'Connor, 1952), Budner's scale (Budner, 1962), Rydell's scale (Rydell & Rosen, 1966), MacDonald (1970), and Norton (1975), by applying a Varimax factor analysis rotation. The results revealed six factors: (1) *problem-solving* (most important), (2) *anxiety*, (3) desire to *complete* a problem, (4) *adventurousness*, (5) *uncertainty seeking,* and (6) *problem fragmentation* (least important). This information is presented in Table 3.2.

Table 3.2

*Factors and Their Labels Assigned by Furnham (1994)*

| Factor | Factor's labels per Furnham |
|---|---|
| Factor 1 | *problem-solving* |
| Factor 2 | *Anxiety* |
| Factor 3 | desire to *complete* a problem |
| Factor 4 | *Adventurousness* |
| Factor 5 | *uncertainty seeking* |
| Factor 6 | *problem fragmentation* |

## 3.9 Development of Exposure to Ambiguity Instrument

The study focuses on the application Furnham's work in higher education specifically. He used 243 subjects, from which "about half completed secondary schooling and the remainder had some post-work qualification" (Furnham, 1994, p. 406). In the current study all subjects were college students enrolled in ABET accredited programs at Purdue University. Based Furnham's emerged factors, a new instrument was developed to measure exposure to ambiguity, both prior to capstone courses and during them. Table 3.3 maps Furnham's factors to MacDonald's survey. It also provides a rationale and basic questions of the study for the instrument. Only one basic question per factor was selected to limit the number of questions in the survey to 36, because each question would be determinated for six different contexts, which will be discussed later.

Table 3.3

*Mapping Furnham's Factors, MacDonald's Questions, Rationale and Basic Exposure to Ambiguity Survey Questions*

| Furnham's factors | MacDonald's Survey Questions | | Rationale | Basic Question |
|---|---|---|---|---|
| ***problem-solving (most important)*** | 3 | There's a right way and a wrong way to do almost everything. | Only Q19 seemed easy to document experientially | I have solved problems that lacked a clear-cut and unambiguous answer. |
| | 7 | Practically every problem has a solution. | | |
| | 9 | I have always felt that there is a clear difference between right and wrong. | | |
| | 11 | Nothing gets accomplished in this world unless you stick to some basic rules. | | |
| | 16 | Perfect balance is the essence of all good composition. | | |
| | 19 | I don't like to work on a problem unless there is a possibility of coming out with a clear-cut and unambiguous answer. | | |
| ***anxiety*** | 2 | I am just a little uncomfortable with people unless I feel that I can understand their behavior. | Using Q6 because engineers tend to be concerned about control (citation) | I have been in social situations over which I had no control. |
| | 6 | I get pretty anxious when I'm in a social situation over which I have no control. | | |
| | 8 | It bothers me when I am unable to follow another person's train of thought. | | |
| | 10 | It bothers me when I don't know how other people react to me. | | |

Table 3.3 continued

| | | | | |
|---|---|---|---|---|
| ***desire to complete a problem*** | 1 | A problem has little attraction for me if I don't think it has a solution. | Q1 seemed more relevant to the topic and is easy to document experientially | I have worked on problems to which I didn't think there was a solution. |
| | 18 | If I were a scientist, it would bother me that my work would never be completed (because science will always make new discoveries). | | |
| | 20 | The best part of working a jigsaw puzzle is putting in that last piece. | | |
| ***adventurousness*** | 4 | I would rather bet 1 to 6 on a long shot than 3 to 1 on a probable winner. | Q1 seemed more relevant to the topic and is easy to document experientially | I have spent time fooling around with new ideas, even if I thought they might turn out to be a total waste of time. |
| | 14 | Sometimes I rather enjoy going against the rules and doing things I'm not supposed to do. | | |
| | 15 | I like to fool around with new ideas, even if they turn out later to be a total waste of time. | | |
| ***uncertainty seeking*** | 13 | Before an examination, I feel much less anxious if I know how many questions there will be. | None of the questions seemed easy to document experientially | Sometimes, I have chosen to work on something simply because I didn't know anything about it. |
| | 17 | If I were a doctor, I would prefer the uncertainties of a psychiatrist to the clear and definite work of someone like a surgeon or X-ray specialist. | | |
| ***problem fragmentation (least important)*** | 5 | The way to understand complex problems is to be concerned with their larger aspects instead of breaking them into smaller pieces. | Q1 seemed more relevant to the topic and is easy to document experientially | In the past, I have been on a team that has split up tasks to make it easier to finish a project. |
| | 12 | Vague and impressionistic pictures really have little appeal for me. | | |

After the basic questions were determinated, the following contexts were used for the survey (Table 3.4):

Table 3.4

*Contexts Applied to Basic Exposure to Ambiguity Survey Questions*

| Survey | Contexts |
|---|---|
| Pre-capstone project | In high school<br>In extracurricular activities in high school<br>In classes outside of my major<br>In classes in my major (except this capstone)<br>In extracurricular activities in college<br>In internships or cooperative education experiences |

The full version of the survey can be found in the Appendix C.

## 3.10 Summary of Data Collection and Analysis

MacDonald's scale (1970) was selected for the current study to measure change or lack of it in the ability to tolerate ambiguity and uncertainty in design. The Fear of Negative Evaluation survey instrument was added to the MacDonald tool to measure levels of anxiety associated with capstone design experience. An IRB approval was received for this study. All students' identifiers were removed after the data was collected. Students were advised not to mention projects they were working on, their names and their teammates' names. As an instructor in one course, the researcher might affect data collected. However, it is less critical in a quantitative study. Also, most of the data was collected by other instructors in their courses.

All characteristics of the study, instruments, and goals are listed in Table 3.5:

Table 3.5

*Quantitative research method, its characteristics, instruments used, and goals, (based on Sieber (1973) and Johnson & Onwuegbuzie (2004))*

| Method | Instruments | Characteristics | Goals |
|---|---|---|---|
| Quantitative | Tolerance for Ambiguity/ Survey/MacDonald (1970)<br><br>Fear of Negative Evaluation Scale (Watson, & Friend, 1969) | True/False responses<br>Standardized data collection<br>Statistical analysis<br>Significance should be equal or less than 0.05<br><br>Deduction<br>Confirmation<br>Theory/hypothesis testing<br>Prediction | Change or lack of it over time |
| | Exposure to Ambiguity (to be developed) | Normal data distribution is desired<br>Data depends on quality of survey<br>Limited view<br>Ease of data collection<br>Limited influence of researcher<br>Strong theoretical expectations | Moderator to the relationship |

A quantitative study of data collected on subjects' tolerance for ambiguity and fear of negative evaluation at the beginning and the end of the project, were performed. A newly-developed Exposure to Ambiguity survey took place in the middle of the experience. Introduction of additional data collection, instead of increasing number of questions of the initial survey, reduced a possible "survey fatigue." The purpose of the survey was to establish levels of exposure to ambiguous situations and projects in different contexts: prior to enrollment in the college, during first three years in college, and during internships or cooperative education experiences.

The statistical method applied to analyze the study data was multiple regressions, where fear of negative evaluation is a predictor and tolerance for ambiguity is an outcome. To understand the relationship better, global exposure to ambiguity (effect of overall experience in a curriculum prior to a capstone course) can serve as a moderator for this relation. The SAS/STAT 9.3_M1 statistical software was used to analyze the data.

# CHAPTER 4. RESULTS AND DISCUSSION

## 4.1 Survey Administration and Data Collected

The literature suggests that online surveys result in lower response rate than face-to-face paper surveys: 43% vs. 75% (Dommeyer, Baum, Hanna, & Chapman. 2004), 30% vs. 65% (Ogier, 2005); 31% vs. 56% (Nair, Wayland, & Soediro, 2005). Because of that, data collection was administered by a face-to-face method. The researcher visited each course considered in the current study and distributed Scantron forms to students to record their responses. The questionnaires were presented via MS PowerPoint slides. Information about the courses, semesters, instructors, total number of students, and number of responses is shown in Tables 4.1 through 4.5:

Table 4.1

*Relationship between Courses and Curricula*

| | Capstone 1/proposal phase | | Capstone 2/implementation phase | |
|---|---|---|---|---|
| School | Course number | Course Description | Course number | Course Description |
| School of Engineering Technology | ECET43000 | Electrical And Electronic Product And Program Management | ECET46000 | Project Design And Development |
| | ECET43100 | International Capstone Project Planning And Design | ECET46100 | International Capstone Project Execution |
| | MET40000 | Mechanical Design | MET49000 | Special Topics In MET |
| School of Aviation and Transportation | AT49600 | Applied Research Proposal | AT49700 | Applied Research Project |

Table 4.2

*Information on Surveys, Timeframe and Instructors of the Courses*

| Survey | School | Course(s) | Date | Instructor |
|---|---|---|---|---|
| Pre-project TfA and FNE | School of Engineering Technology | ECET43000<br>ECET43100<br>MET40000 | 09/23/2015 | Instructor A<br>Instructor B |
| Pre-project TfA and FNE | School of Aviation and Transportation | AT49600 | 09/21/2015 | Instructor C |
| Exposure to Ambiguity | School of Engineering Technology | ECET46000<br>ECET46100<br>MET49000 | 02/05/2016 | Instructor A<br>Instructor B |
| Exposure to Ambiguity | School of Aviation and Transportation | AT49700 | 01/28/2016 | Instructor D* |
| Post-project TfA and FNE | School of Engineering Technology | ECET46000<br>ECET46100<br>MET49000 | 04/15/2016 | Instructor A<br>Instructor B |
| Post-project TfA and FNE | School of Aviation and Transportation | AT49700 | 04/26/2016 | Instructor D* |

Notes: * Instructor D is the author of this study

Table 4.3

*Response Rate of the Pre-project Tolerance for Ambiguity and Fear of Negative Evaluation Surveys*

| Pre-project TfA and FNE surveys, Fall 2015 | | | | |
|---|---|---|---|---|
| Course | Number of students | Notes | Number of responses | Response rate |
| MET 40000 | 27 | All three courses are combined for lectures | 107 | 91% |
| ECET 43000 | 66 | | | |
| ECET 43100 | 25 | | | |
| AT 49600 | 42 | - | 41 | 98% |

Table 4.4

*Response Rate of the Exposure to Ambiguity Survey*

| Exposure to Tolerance survey, Spring 2016 | | | | |
|---|---|---|---|---|
| | Number of students | Notes | Number of responses | Response rate |
| MET 49000 | 27 | Two courses are combined for lectures | 76 | 82% |
| ECET 46000 | 66 | | | |
| ECET 46100 | 25 | - | 10 | 40% |
| AT 49700 | 42 | - | 38 | 90% |

Table 4.5

*Response Rate of the Post-project Tolerance for Ambiguity Survey and Fear of Negative Evaluation Surveys*

| Post-project TfA and FNE surveys, Spring 2016 | | | | |
|---|---|---|---|---|
| | Number of students | Notes | Number of responses | Response rate |
| MET 49000 | 27 | Two courses are combined for lectures | 39 | 42% |
| ECET 46000 | 65 | | | |
| ECET 46100 | 24 | - | 13 | 54% |
| AT 49700 | 39 | - | 38 | 97% |

In the beginning of the proposal phase semester, the response rate was high in all student groups. All capstone courses in the School of Engineering Technology were combined in one lecture, most students were present, and their response rate was 91%. The School of Aviation and Transportation Technology's students are required to attend lectures, even though problem-based learning method was selected. As a result, all administered surveys yielded high response rates: 98% for the Pre-project Tolerance for Ambiguity survey; 90% for the Exposure to Tolerance survey, and 97% for the Post-project Tolerance for Ambiguity survey. The second semester, in the implementation phase of these capstone courses, was different for the School of Engineering Technology's students. Their instructor spent many days traveling and many lectures were cancelled, sometimes without warning. Per observations of the current study's researcher, this affected their attendance and, subsequently, their participation rates. For example, the Exposure to Ambiguity survey was administered to only 10 ECET46100 students (only 40% response rate), who were present at an optional laboratory section. Plus, the shift to a focus on delivering project reports, tangible goods, and perceived overload resulted in a reduction in focus on the importance of lecture attendance (Cerrito & Levi, 1999). This situation is also consistent with courses with unpredictable time dedicated to coursework (Chambers, 1992; Garg, Tuimaleali'ifano, & Sharma, 1998; Garg, Vijayshre, & Panda, 1992). The latter surveys were also more likely to have missing data, which made some surveys unusable.

To ensure that the smaller pool of research subjects is still representing the population of the current study, series of t-tests with two-tail distributions and equal variance assumed were performed. The tests compared responses of the students, who participated in both, pre- and post-, Tolerance for Ambiguity and Fear of Negative Evaluation surveys, with the students, who took part in the initial surveys only at the beginning of the first semester. Each test examined initial participation for both groups of students.

For Tolerance for Ambiguity pre-project survey, no statistical difference was found between the groups: subjects participating in both TfA surveys ($M = 9.63$, $SD = .48$) and those who took part in initial TfA survey only ($M = 9.51$, $SD = .48$), $t(97) = .84$, $p =$ n.s.

For Fear of Negative Evaluation pre-project survey, the first group ($M = 12.11$, $SD = 1.30$) and the second group ($M = 10.85$, $SD = .82$) did not differ significantly on their responses, $t(97) = .86$, $p =$ n.s. Based on those findings, it is possible to claim that final pool of research subjects from the School of Engineering Technology represent the initial group of students from that school.

## 4.2 Data Reduction to Achieve Quality of Input

In addition to the class cancellations and pressure to deliver the projects on time that plagued response rates in the second semester, eight students in the first semester did not record their identification numbers and one was entered incorrectly. While it is possible that most of them participated in the subsequent surveys, it is impossible to verify, so those data were also removed from the sample. Tables 4.6 and 4.7 summarize information presented above.

Table 4.6

*Response Rate and Missing Data of the Pre-project Tolerance for Ambiguity Survey and Fear of Negative Evaluation Surveys*

| Pre-project TfA and FNE surveys, Fall 2015 | | | | | |
|---|---|---|---|---|---|
| Course | Number of responders | Notes | No ID | Missing points | % of usable data |
| MET 40000 | 107 | All three courses are combined for lectures | 9 | 1 | 90.7% |
| ECET 43000 | | | | | |
| ECET 43100 | | | | | |
| AT 49600 | 41 | - | 1 | 0 | 97.6% |

Table 4.7

*Response Rate and Missing Data of the Post-project Tolerance for Ambiguity Survey and Fear of Negative Evaluation Surveys*

| Post-project TfA and FNE surveys, Spring 2016 | | | | | |
|---|---|---|---|---|---|
| Course | Number of responders | Notes | No ID | Missing points | % of usable data |
| MET 49000 | 39 | Two courses are combined for lectures | 0 | 2 | 94.9% |
| ECET 46000 | | | | | |
| ECET 46100 | 13 | - | 0 | 3 | 76.9% |
| AT 49700 | 38 | - | 0 | 0 | 100.0% |

It is not uncommon to receive responses with information missing. For example, Szilagyi and Sims (1975) described the study where 230 out of 1161 were removed because of incomplete information. If multiple rounds of surveys are involved, the number with missing data is typically higher. Caplan and Jones (1975) started with a 94% response rate, which dropped to 60% when only those completing the follow up survey were included.

After cleaning data by discarding responses with incomplete data and counting only responses that could be matched from Fall 2015 to Spring 2016, the total number of complete responses was 62 (see Table 4.8). This is above the recommended minimum number of subjects, which is 10 responses per predictor variable, if six or more predictors are used for regression (Wilson VanVoorhis & Morgan, 2007). Another source (Harris, 1985) suggests using 50 participants plus the number of predictors (which in this study is four). The number of responses in the current study meets both of these criteria.

Table 4.8

*Total Number of Students, Number of Responses, and Number of Full Datasets*

<table>
<tr><th colspan="9">Summary of all surveys</th></tr>
<tr><th colspan="4">Fall 2015</th><th colspan="4">Spring 2016</th><th></th></tr>
<tr><th>Course</th><th>Number of students</th><th>Number of responses</th><th>Discarded</th><th>Course</th><th>Number of students</th><th>Number of responses</th><th>Discarded</th><th>Full datasets</th></tr>
<tr><td>MET 40000</td><td>27</td><td rowspan="3">107</td><td rowspan="3">9</td><td>MET 49000</td><td>27</td><td rowspan="2">39</td><td rowspan="2">2</td><td rowspan="3">26</td></tr>
<tr><td>ECET 43000</td><td>66</td><td>ECET 46000</td><td>65</td></tr>
<tr><td>ECET 43100</td><td>25</td><td>ECET 46100</td><td>24</td><td>13</td><td>3</td></tr>
<tr><td>AT 49600</td><td>42</td><td>41</td><td>1</td><td>AT 49700</td><td>39</td><td>38</td><td>0</td><td>36</td></tr>
</table>

## 4.3 Descriptive Statistics and Correlations between Variables

Descriptive statistics are presented in Table 4.9. Table 4.10 shows that strong positive correlation exists between levels of Fear of Negative Evaluation at the beginning and the end of the projects. Also, there were weak negative correlations between the initial and final Fear of Negative Evaluation and both levels of Tolerance for Ambiguity throughout the projects. Pre- and post- Tolerance for Ambiguity exhibited moderate positive correlation (Evans, 1996). All mentioned correlations were significant.

Table 4.9

*Sample Sizes, Means, Standard Deviations, Minimum and Maximum Values of Variables*

| Variables | N | Mean | Std Dev | Minimum | Maximum |
|---|---|---|---|---|---|
| 1. Pre-project FNE | 146 | 11.26 | 7.44 | 0 | 30 |
| 2. Post-project FNE | 86 | 12.80 | 8.02 | 0 | 30 |
| 3. Pre-project TfA | 147 | 9.39 | 2.89 | 2 | 17 |
| 4. Post-project TfA | 86 | 9.21 | 2.94 | 2 | 16 |
| 5. Exposure to Ambiguity | 124 | 25.78 | 5.95 | 11 | 36 |

Table 4.10

*Pre- and Post-project Survey Instruments: Correlations*

| Variables | N | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1. Pre-project FNE | 146 | - | | | | |
| 2. Post-project FNE | 86 | .78*** | - | | | |
| 3. Pre-project TfA | 147 | -.33*** | -.23**** | - | | |
| 4. Post-project TfA | 86 | -.36** | -.34** | .54*** | - | |
| 5. Exposure to Ambiguity | 124 | -.08 | -.14 | .04 | .22 | - |

Note: *p<.05, **p<.01, ***p<.001, ****p=.05

Individuals with low scores in the pre-project Fear of Negative Evaluation are considered relaxed in social situations; people with middle scores could experience fear in some social situations. High scores mean that subjects are concerned about what other people think about them (Watson & Friend, 1969). The scale of the instrument, and data collected, range from 0 to 30 points maximum. The mean of pre-project FNE was 11.26 (*SD* = 7.44) and mean of post-project FNE was 12.80 (*SD* = 8.02), which means that observed Fear of Negative Evaluation *increased* almost 14% throughout the capstone experience. This is not what was expected, however, one possible explanation of this phenomenon is that the students were exposed to complex problem-based learning for the first time. It could be that they did not anticipate the complexity of the projects and overestimated their social abilities at the beginning of the class. In spite of this possible explanation for an increase in FNE, the measured difference is not significant. The fact that pre- and post-FNE results are strongly and positively correlated was not unanticipated, because the same students provided this data over a year and it is logical that a student's disposition at the start of the year would be related to their disposition at the end.

Since Tolerance for Ambiguity (TfA) is a positive attribute, a greater score means higher tolerance for ambiguity, and a lower number indicates lower tolerance for ambiguity. The score can range from 0 to 20 points (MacDonald, 1970). In this sample, the data ranges from 2 to 17 (pre-project TfA) and from 2 to 16 (post-project TfA). The sample means for Tolerance for Ambiguity decreased from 9.39 (*SD* = 2.89) at the beginning of the project to 9.21 (*SD* = 2.94), which is only a 2% observed reduction and not statistically significant. As expected, pre- and post- Tolerance for Ambiguity results were positively correlated, since radical changes in this construct are unlikely.

Lastly, while the Exposure to Ambiguity scale ranges from 0 to 36 possible points, the sample minimum was 11, which means all students reported previous exposure to ambiguous projects prior to the capstone courses. The sample mean of 25.78 (*SD* = 5.95) is 72% of the instrument's maximum, which suggests that students generally reported a high level of prior exposure.

It was hypothesized that both pre- and post-Tolerance for Ambiguity would be negatively correlated with both sets of Fear of Negative Evaluation, and the results bore out this hypothesis. It was anticipated that individuals with higher levels of tolerance for ambiguity are more relaxed in social situations (Dadds, Barrett, Rapee, & Ryan, 1996).

## 4.4 Regression Analysis

Two regression models are represented in Figures 4.1 and 4.2 detailed views of the hypothesized model in Figure 3.1 of Chapter 3:

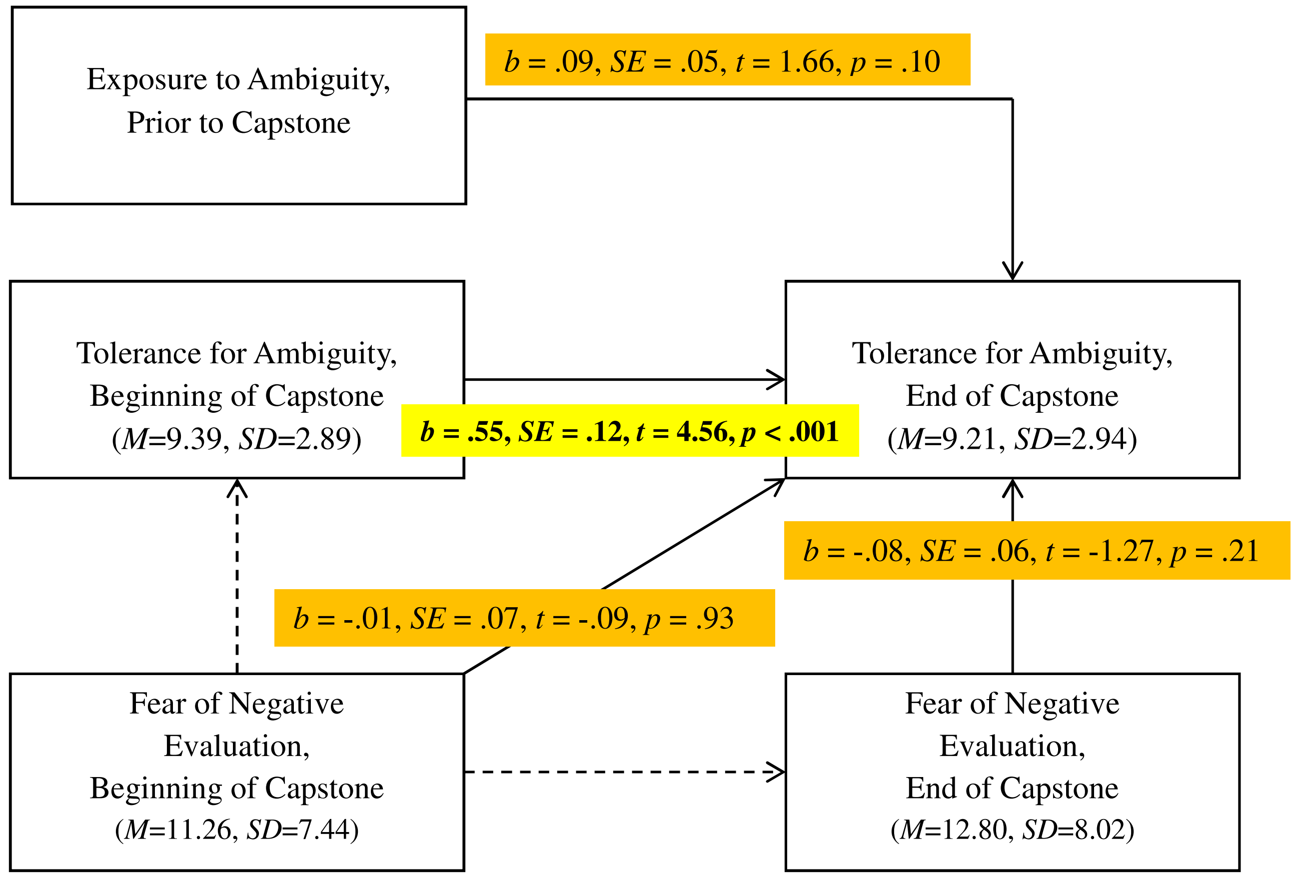


Figure 4.1: Using Fear of Negative Evaluation to Predict Tolerance for Ambiguity at the End of Project Courses

The regression analysis showed that the initial model (see Figure 4.1) significantly predicted Tolerance for Ambiguity at the end of the projects: $F$ (4, 57), $p$ <.001, $R^2$ = .40. The only significant predictor in the model was Tolerance for Ambiguity at the beginning of the projects: $b$ = .55, $SE$ = .12, $t$ = 4.56, $p$ < .001. So in this model, past behavior is the best predictor.

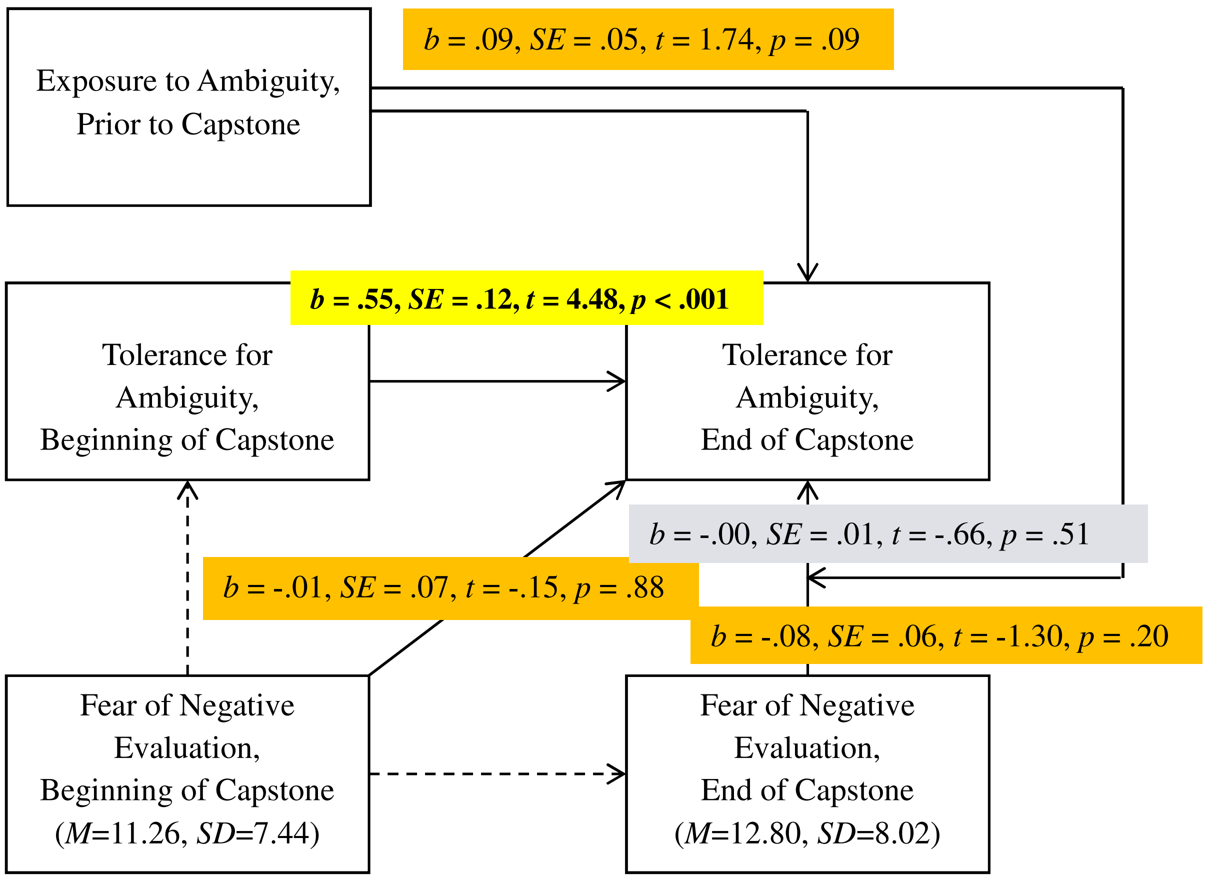


Figure 4.2: Using Fear of Negative Evaluation to Predict of Tolerance for Ambiguity at the End of Project Courses with Exposure to Ambiguity as Moderator

The result from the regression model shown in Figure 4.1 would be disappointing, except that the more important hypothesis in this study was whether prior Exposure to Ambiguity, or number of experiences to ambiguous situation outside of the capstone courses, would have a moderating effect. The model shown in Figure 4.2 tested if the Exposure to Ambiguity moderated the relationship between the Tolerance for Ambiguity at the end of the projects and other predictors. In other words, the goal was to test if the association between the Post-project Tolerance for Ambiguity and Pre-project Tolerance for Ambiguity, Pre- and Post-project Fear of Negative Evaluation varied by level of Exposure to Ambiguity. All four predictor variables were centered and the interaction of the new variables was tested. The results exhibited that overall new model remained statistically significant: $F$ (5, 56) = 7.59, $p < .001$, $R^2 = .40$, but the model did not significantly improve the prediction of Post-project Tolerance for Ambiguity: $F$ (1, 56) = .43, $p = .51$, $\Delta R^2 = 0$. The results are presented in Table 4.11.

Table 4.11

*Predictors for Post-project Tolerance for Ambiguity*

| Model | $R^2$ | Pre-project TfA | Exposure to Ambiguity |
|---|---|---|---|
| A | 0.40 | p<.001 | p = .10 |
| B | 0.40 | p<.001 | p = .09 |

While not originally hypothesized, the different instructor practices observed suggested the possibility that instructor differences could affect the study, so instructor effects were explored. The introduction of instructor effects results in updated models, which are shown in Figures 4.3 and 4.4.

The regression analysis on updated model A’ (see Figure 4.3) showed that it predicted the Tolerance for Ambiguity in the end of the projects: $F$ (5, 56), $p$ <.001, $R^2 = .43$. Again, only Tolerance for Ambiguity in the beginning of the projects was statistically significant: $b = .54$, $SE = .12$, $t = 4.49$, $p < .001$.

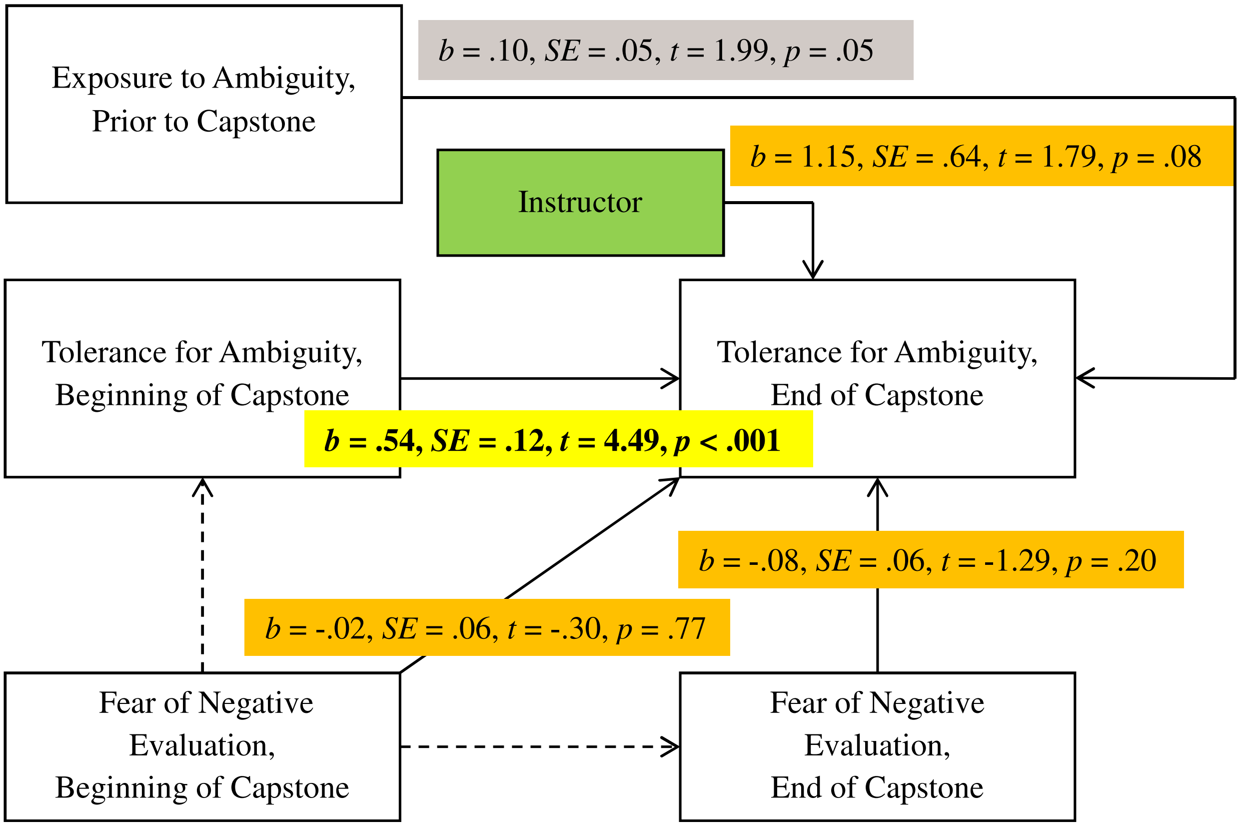


Figure 4.3: Instructor Effects in Predicting of Tolerance for Ambiguity in the End of the Project Courses

The model B' shown in Figure 4.4 tested if the Exposure to Ambiguity moderated the relationship between the Tolerance for Ambiguity in the end of the projects and other predictors in the expended model. All five predictor variables were centered and the interaction of the new variables was tested. The new model was statistically significant: $F$ (6, 55) = 7.05, $p < .001$, $R^2 = .43$. While this revised model did not significantly improve the prediction of Post-project Tolerance for Ambiguity: $F$ (1, 55) = .24, $p = .62$, $\Delta R^2 = .03$, this model did show that the Exposure to Ambiguity was statistically significant: $b = .11$, *SE* = .05, *t* = 2.02, *p* < .05 while controlling for instructor differences. This means that one unit increase in Exposure to Ambiguity leads to .11 units increase in Post-project Tolerance for Ambiguity. On its own, the direct effect of instructor on Tolerance for Ambiguity was not statistically significant: *b* = 1.12, *SE* = .65, *t* = 1.72, *p* = .09. This suggests that the instructors did not affect student attitudes directly, but influenced how they processed their previous experiences with ambiguity. Again, to measure this effect was not in the scope of this study. To help to facilitate this future work, additional information on differences in instructional methods is presented in Table 4.12. The combined results are presented in Table 4.13.

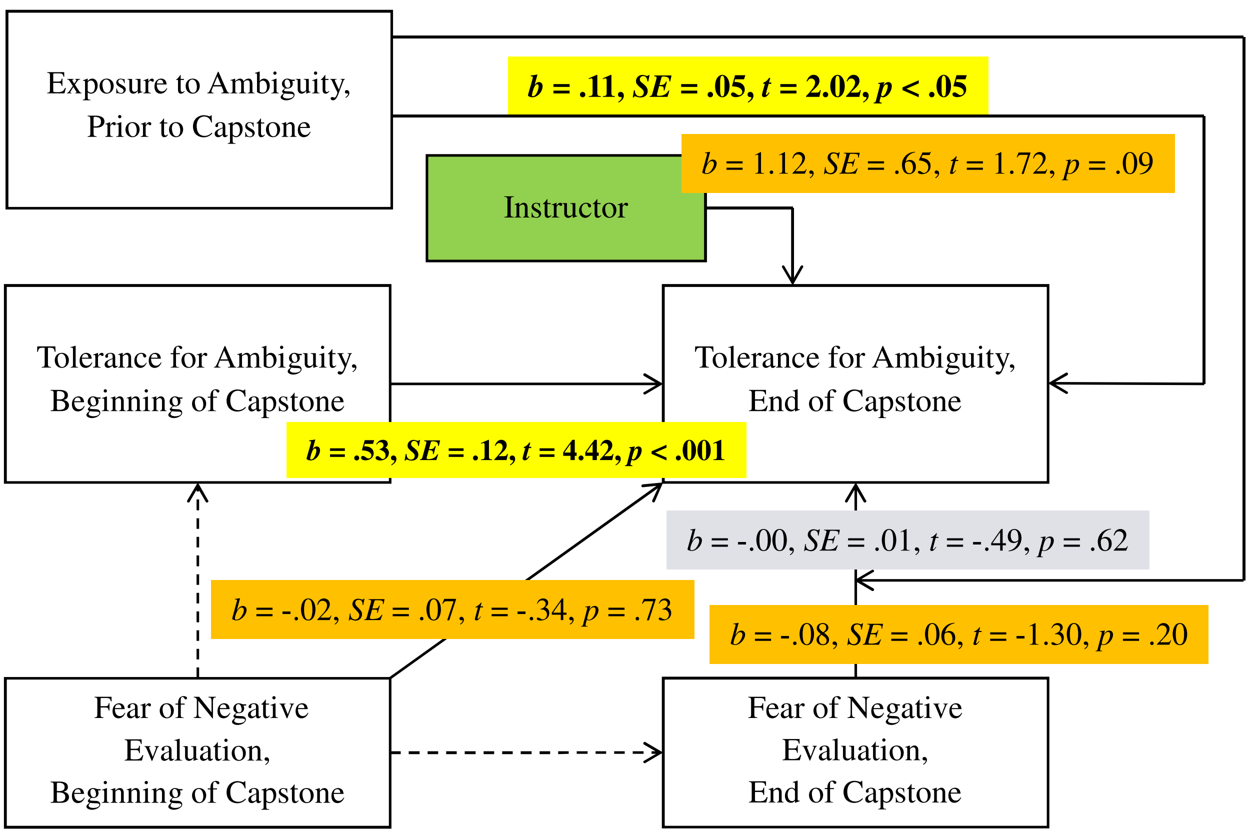


Figure 4.4: Instructor Effects in Predicting Tolerance for Ambiguity at the End of Project Courses when Exposure to Ambiguity is included as a Moderator

Table 4.12

*Summary of Differences and Similarities in Instructional Methods in the Study*

| Attributes | School of Engineering Technology | School of Aviation and Transportation Technology |
|---|---|---|
| Active learning | Problem-based | Problem-based |
| Project management | Six Sigma/Gate reviews | Six Sigma/Gate reviews |
| Number of students in the courses | 118 | 40 |
| Number of teams per mentor/instructor | 1 to 2 | 10 |
| Number of students per mentor/instructor | up to 15 | 40 |
| Monetary reward for mentoring | $2,000 per team | None |

Table 4.13

*Combined Results for Predictors for Post-project Tolerance for Ambiguity, Initial and Updated Models*

| Model | $R^2$ | Pre-project TfA | Exposure to Ambiguity | Instructor | Moderator |
|---|---|---|---|---|---|
| A | 0.40 | p<.001 | p = .10 | - | - |
| B | 0.40 | p<.001 | p = .09 | - | Exposure |
| A' | 0.43 | p<.001 | p = .05 | p = .08 | - |
| B' | 0.43 | p<.001 | p < .05 | p = .09 | Exposure |

# CHAPTER 5. CONCLUSIONS

The study was designed to test the following research hypotheses:

- Tolerance for ambiguity will increase after completion of a capstone course.
- Fear of negative evaluation will decrease after completion of a capstone course.
- Earlier exposure to ambiguity in a curriculum will decrease fear of negative evaluation during a capstone course.
- Earlier exposure to ambiguity in a curriculum will increase tolerance for ambiguity during a capstone course.
- Fear of negative evaluation will be negatively proportional to tolerance for ambiguity.

From the previous chapter, one can notice that the first two hypotheses were rejected. The students demonstrated that the capstone courses had no significant effect on their Tolerance for Ambiguity or their Fear of Negative Evaluation, which was not expected. A possible explanation for this finding is that the students experienced such intense involvement in their own education for the very first time. That is, at the beginning of their projects, they did not expect to experience either negative evaluation or ambiguity. If this were the case, the potential improvement that might have resulted from the project experiences was countered by the resistance due to their novelty. This is consistent with the literature that active learning tends to receive resistance form students, because it is very different from the traditional lecture-based courses. Students go through all or, most likely, the initial stages of grief, such as shock, denial, and resistance (Felder & Brent, 1996; Woods (1994). Unfortunately, it seems that the other, more advanced stages of this process, such as acceptance, exploration, implementation, and success could not be reached by all students in a single course.

As it was shown in the previous chapter, without controlling for instructors only one variable, Tolerance for Ambiguity at the beginning of the projects, predicted Tolerance for Ambiguity at the end of the projects. No other variables were statistically significant, including Fear of Negative Evaluation at both time points. However, Exposure to Ambiguity was a significant predictor of Tolerance for Ambiguity at the end of the projects when controlling for instructor. There was no evidence that the previous exposure to ambiguity altered Fear of Negative Evaluation throughout the projects. The effect of difference in the instructors was not in the scope of this study. However, it suggests that the instructors themselves did not directly affect the students, but they influenced learners' previous experiences with ambiguity.

Lastly, the study verified that Fear of Negative Evaluation and Tolerance for Ambiguity were negatively correlated, but the former could not be used to predict the latter, because its effect was not statistically significant.

As it was stated, this study examined the main topics:

- What is the association between tolerance for ambiguity and fear of negative evaluation at the beginning and the end of engineering technology capstone courses?

- How does exposure to ambiguity prior to capstone courses affect tolerance for ambiguity?

Both questions were answered. Fear of Negative Evaluation surveys in the beginning and the end of the projects did not predict the final Tolerance for Ambiguity. Fear of Negative Evaluation does not affect Tolerance for Ambiguity in senior engineering capstone courses. This is an important finding, because it indicates that social anxiety, as measured by fear of negative evaluation, does not play a major role in capstone courses. When students are working in teams, it was predicted that social interactions between group members and possibility of anxiety could potentially reduce the effectiveness of problem-based learning. This study suggests that this may not be a concern—that this is not likely to be an impediment to implementing active learning.

The second finding is that a single course, even if it was administered as a problem-based senior class, failed to increase students' tolerance for ambiguity. Students with low tolerance have more problems with ambiguity, whereas students with high tolerance can more easily endure changes and find it easier to act in the absence of complete information. This is in line with previously mentioned lack of time needed to fulfil the whole cycle of the grieving process associated with active learning. For future work, it is important to investigate if a multitude of project- and problem-based courses throughout curricula would better condition students to tolerate ambiguity and prepare them for an ever-changing profession.

The third important finding was that exposure to ambiguity prior to capstone courses does affect tolerance for ambiguity while controlling for instructor and if exposure to ambiguity is included as a moderator. This recalls earlier research findings that the guidance of an experienced instructor helps to reduce or maintain both ambiguity and uncertainty (Klahr & Nigam, 2004; Mayer, 2004). It was not in the scope of this study to explore the effect of instructor more deeply, but this provides a direction for future research, especially in this time of expanding implementation of project- and problem-based learning methods in technical curricula.

The findings of the current study have a potential to enrich expected curricular changes for many engineering technology programs in general and for the Purdue Polytechnic Institute, as the research site for the study, in particular. There is much reliance in lecture-based and project- and problem-based courses on grades. Grades earned by the students in the courses were not taken into consideration in the current study, because of difficulty of grading students' contribution in active learning (Kilpatrick, 1921). However, there are many ways exist to assess students' performance using peer evaluation, which is a preferred method of assessment in active learning (Kaufman, Felder, & Fuller, 2000; Kelley, 2015; Ohland, Loughry, Woehr, Layton, & Ferguson, 2015).

For future work, it is needed to investigate this effect by collecting data on differences in teaching methods applied, or, even better, by implementing a shared pedagogical approach administering courses. The latter will be preferred and already partially took place in the current study. The observed classes have many common elements, like using the gate review system, Six Sigma methodology and common tools, and similar elements of project management. It would be beneficial to standardize the course requirements and final deliverables. Also, it might be possible to consolidate the courses. This action would bring diversity to student teams and better represent participation in industry projects. It could also address the differences in mentoring techniques. In the School of Engineering Technology, most mentoring was provided by the designated paid mentors, who worked with fewer students. This was different from the School of Aviation and Transportation Technology, where the course instructor provided most of support to the whole class. Another item to consider is to take into account the difference in complexity of the projects. During the current study, it was noted that students with higher tolerance for ambiguity selected more complex and less defined projects. Less adventurous students tried to stay with less ambitious problems. However, lack of experience in recognizing engineering complexity did not necessary allowed the students to make their choice accurately. One is approaches for future investigation could be involving a panel of experts to review complexity of the problem or projects. In this case, more objective representation of difficulty could be reached. Another method could be allowing instructors, mentors, sponsors, and students themselves to rate the projects and problems. Combining responses and evaluating them would give the better understanding of the topic. This could be an additional independent item in the follow-up studies, as well as students' grades as described before.

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# APPENDICES

Appendix A Fear of Negative Evaluation Survey

Last 4 Digits of your PU ID: ________________________ Date: __________________

This questionnaire is composed of 30 statements regarding your confidence with other people. Circle YES if you consider that the statement if true of your feelings most of the time. Circle NO if you consider that the statement is rarely true of you. Remember that this information is completely ***<u>confidential</u>***

| | |
|---|---|
| | **Please circle** |
| I rarely worry about seeming foolish to others | **YES NO** |
| I worry about what people will think of me even when I know it doesn't make any difference | **YES NO** |
| I become tense and jittery if I know that someone is sizing me up | **YES NO** |
| I am unconcerned even if I know that people are forming an unfavorable impression of me | **YES NO** |
| I feel very upset when I commit some social error | **YES NO** |
| The opinions that people have of me cause me little concern | **YES NO** |
| I am often afraid that I may look ridiculous or make a fool of myself | **YES NO** |
| I react very little when other people disapprove of me | **YES NO** |
| I am frequently afraid of other people noticing my shortcomings | **YES NO** |

| | |
|---|---|
| The disapproval of others would have little effect on me | **YES**<br>**NO** |
| If someone is evaluating me I expect the worst | **YES**<br>**NO** |
| I rarely worry about what kind of impression I am making on someone | **YES**<br>**NO** |
| I am afraid that others will not approve of me | **YES**<br>**NO** |
| I am afraid that others will find fault with me | **YES**<br>**NO** |
| Other people's opinions of me do not bother me | **YES**<br>**NO** |
| I am not necessarily upset if I do not please someone | **YES**<br>**NO** |
| When I am talking to someone, I worry about what they may be thinking of me | **YES**<br>**NO** |
| I feel that you can't help making social errors sometimes, so why worry about it | **YES**<br>**NO** |
| I am usually worried about what kind of impression I make | **YES**<br>**NO** |
| I worry a lot about what my superiors think of me | **YES**<br>**NO** |
| If I know someone is judging me, it has little effect on me | **YES**<br>**NO** |
| I worry that others will think I am not worthwhile | **YES**<br>**NO** |
| I worry very little about what others may think of me | **YES**<br>**NO** |

| | **Please circle** |
|---|---|
| Sometimes I am too concerned with what other people may think of me | **YES NO** |
| I often worry that I will say or do the wrong things | **YES NO** |
| I am often indifferent to the opinions others have of me | **YES NO** |
| I am usually confident that others will have a favorable impression of me | **YES NO** |
| I often worry that people who are important to me won't think very much of me | **YES NO** |
| I brood about the opinions my friends have about me | **YES NO** |
| I become tense and jittery if I know I am being judged by my superiors | **YES NO** |

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# Appendix B MacDonald Survey

Last 4 Digits of your PU ID: ________________________ Date: ___________________

**Instructions**: Please do not spend too much time on the following items. There are no right or wrong answers and therefore your first response is important. Mark ***T*** for true and ***F*** for false. Be sure to answer every question.

**Statements**:

____ 1. A problem has little attraction for me if I don't think it has a solution.

____ 2. I am just a little uncomfortable with people unless I feel that I can understand their behavior.

____ 3. There's a right way and a wrong way to do almost everything.

____ 4. I would rather bet 1 to 6 on a long shot than 3 to 1 on a probable winner.

____ 5. The way to understand complex problems is to be concerned with their larger aspects instead of breaking them into smaller pieces.

____ 6. I get pretty anxious when I'm in a social situation over which I have no control.

____ 7. Practically every problem has a solution.

____ 8. It bothers me when I am unable to follow another person's train of thought.

____ 9. I have always felt that there is a clear difference between right and wrong.

____ 10. It bothers me when I don't know how other people react to me.

____ 11. Nothing gets accomplished in this world unless you stick to some basic rules.

____ 12. If I were a doctor, I would prefer the uncertainties of a psychiatrist to the clear and definite work of someone like a surgeon or X-ray specialist.

____ 13. Vague and impressionistic pictures really have little appeal for me.

____ 14. If I were a scientist, it would bother me that my work would never be completed (because science will always make new discoveries).

____ 15. Before an examination, I feel much less anxious if I know how many questions there will be.

____ 16. The best part of working a jigsaw puzzle is putting in that last piece.

____ 17. Sometimes I rather enjoy going against the rules and doing things I'm not supposed to do.

____ 18. I don't like to work on a problem unless there is a possibility of coming out with a clear-cut and unambiguous answer.

____ 19. I like to fool around with new ideas, even if they turn out later to be a total waste of time.

____ 20. Perfect balance is the essence of all good composition.

Appendix C Exposure to Ambiguity survey

Course ________________ Last 4 Digits PUID ____________________ Date ____________

**Instructions**: Please do not spend too much time on the following items. There are no right or wrong answers and therefore your first response is important. Be sure to answer every question. Remember that participation in this survey is **voluntary** and information is completely **confidential. You must be over 18 years old to participate.**

| **Question** | **Contexts** | **Answer** | |
|---|---|---|---|
| I have solved problems that lacked a clear-cut and unambiguous answer | In high school | Yes | No |
| | In extracurricular activities in high school | Yes | No |
| | In classes outside of my major | Yes | No |
| | In classes in my major (except this capstone) | Yes | No |
| | In extracurricular activities in college | Yes | No |
| | In internships or cooperative education experiences | Yes | No |
| I have been in social situations over which I had no control | In high school | Yes | No |
| | In extracurricular activities in high school | Yes | No |
| | In classes outside of my major | Yes | No |
| | In classes in my major (except this capstone) | Yes | No |
| | In extracurricular activities in college | Yes | No |
| | In internships or cooperative education experiences | Yes | No |
| I have worked on problems to which I didn't think there was a solution | In high school | Yes | No |
| | In extracurricular activities in high school | Yes | No |
| | In classes outside of my major | Yes | No |
| | In classes in my major (except this capstone) | Yes | No |
| | In extracurricular activities in college | Yes | No |
| | In internships or cooperative education experiences | Yes | No |
| I have spent time fooling around with new ideas, even if I thought they might turn out to be a total waste of time | In high school | Yes | No |
| | In extracurricular activities in high school | Yes | No |
| | In classes outside of my major | Yes | No |
| | In classes in my major (except this capstone) | Yes | No |
| | In extracurricular activities in college | Yes | No |
| | In internships or cooperative education experiences | Yes | No |

| | | | |
|---|---|---|---|
| Sometimes, I have chosen to work on something simply because I didn't know anything about it | In high school | Yes | No |
| | In extracurricular activities in high school | Yes | No |
| | In classes outside of my major | Yes | No |
| | In classes in my major (except this capstone) | Yes | No |
| | In extracurricular activities in college | Yes | No |
| | In internships or cooperative education experiences | Yes | No |
| In the past, I have been on a team that has split up tasks to make it easier to finish a project | In high school | Yes | No |
| | In extracurricular activities in high school | Yes | No |
| | In classes outside of my major | Yes | No |
| | In classes in my major (except this capstone) | Yes | No |
| | In extracurricular activities in college | Yes | No |
| | In internships or cooperative education experiences | Yes | No |

If you are interested in being interviewed to help us understand your capstone course experiences, please provide your email address in the text box below.

# VITA

# VITA

SERGEY DUBIKOVSKY

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## EDUCATION

Doctor of Philosophy

College of Engineering, Purdue University, West Lafayette, Indiana,

Engineering Education, December, 2016

Unified Bachelor and Master of Science

South Ural Technical University (formerly Chelyabinsk Polytechnic Institute),

Chelyabinsk, Russia,

Mechanical Engineering, March, 1985

TEACHING EXPERIENCE

Purdue University, Assistant Professor, West Lafayette, IN

*August 2006 to June 2012*

Purdue University, Associate Professor, West Lafayette, IN

*July 2012 to present*

- Faculty member of the School of Aviation and Transportation Technology, Purdue Polytechnic Institute, West Lafayette campus.
- Teaching AT308, Materials and Manufacturing Processes in Aviation course.
- Teaching AT496, Applied Research Proposal course/capstone.
- Teaching AT497, Applied Research Project course/capstone.

Military College Instructor (Tank Corps), Chelyabinsk, Russia

*Sept., 1987 to Mar. 1994*

- Responsibilities included teaching maintenance and repair to future tank corps officers, with an emphasis on personal armored carriers and main battlefield tanks.

RESEARCH AREAS

- Ambiguity of the design process and engineering projects
- Tolerance for ambiguity and social anxiety in the senior design courses/process
- Immersive and problem- and project-based learning
- International engineering education

RECENT INDUSTRIAL EXPERIENCE

Caterpillar/Butler International, Product Engineer, Lafayette, IN

*Nov., 2005 to Aug. 2006*

- Developed starting, cooling and lubrication systems for new C175 engine and maintained existing 3500 series engines to meet customer requirements. Worked as a member of Six Sigma teams to develop, design, redesign and identify product requirements to meet the customer expectations. Involved in the Speed Timing Sensor project which saved over one million dollars in Lever I benefits, and over 9 million dollars in Lever III benefits. Successfully performed in a team environment to resolve product related problems that improve production deliverables, improve product quality and reliability. Modeling skills with Pro-Engineer 3D parametric software. Extensive testing experience with machine application diesel engines, selection of materials, specifications, and production process improvement. Effective problem solving.
- Involved in determining feasibility of product modifications and new product design. Worked with representatives of national and international suppliers. Collaborated with CAT India and Butler India design centers.

Workhorse Custom Chassis, Product Engineer / Structures, Union City, IN

*Aug., 2002 to Nov. 2005*

- Developed and maintained new and existing products to meet customer requirements. Worked with sales and customers to develop, design, redesign and identify product requirements to meet the customer expectations. Successful in a team environment to resolve product related problems that improve production deliverables, improve product quality and reliability. Performed bolted joints calculations for all critical applications, including frame and all sub-systems of step van, bus, and RV custom vehicle chassis. Involved in implementation of specialized fasteners into chassis designs, including Huck fasteners. Performed strength of materials calculations, design and Finite Element Analysis of structural components for new products. Experience with Unigraphics, structural analysis (Scenario and I-deas), and 3D modeling. Extensive testing experience with custom chassis, both new RV and bus. Experience with selection of materials, specifications and production process improvement. Effective problem solving. Established component Bill of Materials for new products. Created a complete product drawing package in compliance with company and QS-9000 standards.
- Member of market research team. Involved in determining feasibility of product modifications and new product design. Converted customer wishes and requirements into technical design specifications. Worked with representatives of national and international suppliers. Collaborated with South African sister company Truck Engineering Services (TES).

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