ABSTRACT

KELLY, DANIEL PATRICK. Measurements of self-efficacy in engineering graphics students: An examination of factors impacting student outcomes in an introductory engineering graphics course. (Under the direction of Dr. Aaron C. Clark).

This dissertation is intended to examine the effect of self-efficacy in engineering graphics, a domain which lacks comprehensive study with respect to a construct researchers have demonstrated has a significant impact on achievement, persistence, and outcomes. An introductory undergraduate engineering graphics course was surveyed over four semesters to acquire the data analyzed. This dissertation examines self-efficacy in engineering graphics education with three distinct studies to gain insight into the effect of three-dimensional modeling self-efficacy in an engineering graphics course.

The first article examines a three-dimensional modeling self-efficacy instrument for evidence of reliability and validity, and assesses the individual items using an existing dataset of middle and high school students. Demographic differences were also examined and no differences in self-efficacy scores between males and females were found in the study.

The second article presents the methods and findings of the psychometric investigation using a population of 503 undergraduate students enrolled in an introductory engineering graphics course. The Three-Dimensional Modeling Self-Efficacy scale examined in this study was found to have strong evidence of reliability and validity and an exploratory factor analysis revealed a single factor structure underlying the instrument. This research adds to the literature evidence toward the validation of a domain-specific instrument for use in engineering graphics education.

The third article examines gender differences in self-efficacy among engineering students in an undergraduate introductory engineering graphics course. Self-efficacy is
directly linked to persistence in both college and career and an area of study lacking in engineering graphics education research. Research has shown that women in engineering education perform on par academically but have significantly lower levels of self-efficacy. This research confirms that these trends extend into engineering graphics, a required subject for many, if not most, students pursuing engineering degrees.

In aggregate, these manuscripts provide evidence of the reliability and validity of the Three-Dimensional Modeling Self-Efficacy scale used in this study and contributes this evidence to the field of engineering graphics which lacks a domain specific self-efficacy instrument. This dissertation also provides evidence confirming that the gender gap issues present in engineering education generally are present in engineering graphics education as well.
Measurements of self-efficacy in engineering graphics students: An examination of factors impacting student outcomes in an introductory engineering graphics course

by

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DEDICATION

This dedication has been a long time in the works. I have waited for this occasion to dedicate the culmination of my education and work thus far to a person who helped me at the beginning of my journey and whom I wish could be here for this stop along the way. My grandmother served as my foundation and my motivation and her counsel is deeply missed. Her generosity and sacrifice will never be repaid, but will be paid forward. I dedicate this dissertation to her, her love, her support, etc, etc, etc…
BIOGRAPHY

Daniel Patrick Kelly was born on April 21, 1980 in North Tonawanda, New York. He enlisted in the United States Navy upon graduation from Niagara-Wheatfield High School in Sanborn, New York. Daniel completed his Bachelor of Arts degree in Physics at the State University of New York College at Potsdam where he also studied Secondary Science Education as a graduate student.

Daniel completed his Master of Science in Technology Education at North Carolina State University in 2015 after teaching middle school technology and engineering courses in Durham, North Carolina. He immediately pursued a Doctor of Education degree in Technology Education where he worked as a Graduate Research Assistant and Graduate Teaching Assistant. Daniel joined the Technology Education faculty as a Lecturer in the fall of 2017.

Daniel Kelly has served his community as a volunteer firefighter, EMT, and currently uses the proceeds of his book *Falling Down* to support a non-profit organization he founded to help at-risk youth and families. His non-profit, The PUSH Initiative, has begun working on STEM Education outreach for local students in foster care and Daniel is merging this public service work with his research and teaching interests.

Daniel Kelly is currently seeking a position as a tenure-track professor. He hopes to use the skills learned through his studies to positively impact the educational outcomes of at-risk students.
AKNOWLEDGMENTS

The absolutely enormous number of people needed to support someone through more than a decade of higher education and the rigors of doctoral study are countless. I would like to recognize a few who have quantifiably helped me become the burgeoning scholar I am today.

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To my friends and colleagues: I have had the pleasure to work with some of the best people I have ever known. Your passion is a stalwart example of the environment I hope to be able to continue to work in. I hope these relationships will help all of us to better ourselves as scholars and educators.
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Chapter 1

Introduction

Recent history has provided a continually growing demand for trained STEM professionals with no indication of those trend lines reaching apogee in the near future. Projections for engineering jobs specifically point to steady growth over the next decade and a looming period of greater increased demand as “baby-boomers” holding those positions reach retirement age (NSF, 2016). To remain globally competitive, the United States will need to produce one million new STEM professionals over the next decade (NSF, 2016). This increasing demand is evident in the White House (2009) Educate to Innovate initiative to prepare and train 100,000 STEM educators by 2020. Part of that initiative is the acknowledgment that women and ethnic minorities are significantly underrepresented in this crucial fields (Godwin, Potvin, Hazari, & Lock, 2016; White House, n.d.).

If the prediction and fulfillment of a needed one million more trained professionals and the historical pattern of only 35% of engineering and 14% of science graduates actually entering the workforce (NSF, 2016) continue to hold true, science and engineering education, as well as supporting programs will see a remarkable increase in enrollment. While enrollment increases and more diversity initiatives are developed and successful, there will be a demographic shift in the students enrolled in STEM education at all levels. Current pedagogical practices and research have been developed based on populations historically present in engineering courses. These demographic changes necessitate an examination of how STEM courses are taught and if the needs and demands of historically underrepresented
groups are being met (Duderstadt, 2007). An understanding of the educational needs and dynamics of these groups is essential if there is to be a sincere effort to recruit retain members of this group both in educational settings and industry.

Engineering graphics is a required area of study for many engineering programs and courses in the discipline have some of the highest enrollment in STEM education (Sadowski & Sorby, 2013). Although not specifically engineering, literacy in engineering graphics communication is necessary for success in the profession. Engineering has a long history of utilizing graphics linguistically, and graphics continue to be the preferred method for the communication of designs and ideas (Barr, 2013). Even with the technological changes in the manner by which engineering graphics have been created - from the grid lines drawn on papyrus in ancient Egypt to Vitruvian multi-view projections to the sophisticated parametric 3-dimensional software of today - this trend does display any indication of changing (Barr, 2013; Branoff, Hartman, & Wiebe, 2002). However, as we encounter greater participation of demographic groups not previously represented in substantial numbers, increasing numbers of students to meet demand, greater diversity in academic ability due to a widening participant pool, and instructional changes as more computer dependent practices are used, there is a need to understand how these changes impact student outcomes (Duderstadt, 2007).

Course, project, and exam grades provided a convenient means of comparison between groups, but provide only a superficial view of the outcomes that can be impacted by pedagogical and instructional practices. Understanding the underlying affective, psychomotor, and cognitive contributions to metrics such as grades are needed to analyze the
outcomes and adjust instructional practices to address the needs of students more effectively and positively impact those factors that offer the best outcomes for students in both the short and long term. Affective, psychomotor, and cognitive domains are three overlapping taxonomies of acquisitional learning that address the products of learning such as knowledge, skills, attitudes, and behavior (Noorhidawati, Ghalebandi, & Hajar, 2015; Rovai, Wighting, Baker, & Grooms, 2009).

To guide the research plan and implementation, Figure 1.1 below represents the steps the researcher will take through this process.

*Figure 1.1. Research plan.*
Justification and Rationale

With the need for greater numbers of practitioners in STEM fields increasing over the next decade and demonstrated deficits in post-secondary students persisting through graduation, and students who complete degree programs in engineering continuing on to careers in that field, an examination of possible solutions to address this problem is needed. This study examines methods by which researchers measure one component related to academic achievement and persistence, self-efficacy. It is well established in the literature that self-efficacy is a reliable predictor of academic performance and persistence within specific domains (Fantz, Siller, & Demiranda, 2011; Lent, Brown, & Hackett, 1994; Pajares, 1996). Given the domain-specificity of self-efficacy requirements and self-efficacy assessment scales (Bandura, 2006), it is crucial to have measurements designed and validated within the domain of study.

Currently, the dearth of self-efficacy research in engineering graphics within the extant literature has also meant that domain specific and validated self-efficacy instruments have not been added to or discussed within that literature. Metraglia, Villa, Baronio, & Adamini (2016) investigated self-efficacy within introductory engineering graphics but used the self-efficacy portion of the Motivations for Student Learning Questionnaire (MSLQ) rather than a domain specific instrument. This study examines one domain-specific self-efficacy instrument and one general self-efficacy of learning instrument in order to contribute to the discourse in the field of engineering graphics validity evidence of an instrument with which to measure the levels of self-efficacy among engineering graphics students. The
addition and use of this instrument to researchers and educators within engineering graphics will allow for the assessment, discussion, and possible inclusion of self-efficacy into curricular, course, and programmatic design and reform in an effort to increase the number of students both entering and persisting in fields requiring the use of engineering graphics.

**Problem Statement**

The literature is replete with studies on student self-efficacy and its effect on student behavior and, in turn, performance (Fantz et al., 2011). Self-efficacy also has strong predictive validity with student achievement outcomes and persistence (Pajares, 1997). Although self-efficacy research in education is well established in the literature, self-efficacy research within engineering graphics education is sparse in the extant literature. An index search (Web of Science, ERIC, and Google Scholar) returned only one study related to self-efficacy in engineering graphics (Metraglia, Villa, Baronio, & Adamini, 2016). This notable dearth in the extant literature leaves the impact of instructional practices and materials in engineering graphics on student self-efficacy levels unstudied and unknown. This research is needed to better inform practice and methods within engineering graphics instruction especially considering that lower levels of self-efficacy are shown to decrease the desire to persist in engineering (Godwin, Potvin, Hazari, & Lock, 2016).

**Scope of Study**

The learning domains of affective, behavioral, and psychomotor are too complex for a single study to use as a framework with which to examine the underlying structures that contribute to student outcomes. Broadly, this study will focus on the affective (emotional)
domain which encompasses feelings, values, appreciation, enthusiasms, motivations, and attitudes (Krathwohl, Bloom, & Masia, 1974). Self-efficacy is identified as being associated with the affective domain (Lent, Brown, & Larkin, 1984). Narrowly, this study will be limited to an examination of the contribution of a student’s reported levels of self-efficacy on their academic outcomes as measured by their final course, final project, and final exam grades. Self-efficacy will be evaluated using a domain specific Three-Dimensional Modeling Self-Efficacy instrument (adapted from Denson & Hill, 2010) and a general Self-Efficacy for Learning (Klobas, Renzi, & Nigrelli, 2007) scale to compare the results and identify any common elements of the two assessments.

Research Questions

To guide this research, the following research questions were asked:

RQ1. Is there evidence that the domain-specific Three-Dimensional Modeling Self-Efficacy scale reliable?

RQ2. Is there evidence of validity in the domain-specific Three-Dimensional Modeling Self-Efficacy scale?

RQ3. What effect does a student’s three-dimensional modeling self-efficacy have on their academic outcomes in an undergraduate introductory engineering graphics course?

RQ4. To what extent do the results and contributions of the general self-efficacy of learning and domain-specific 3D modeling self-efficacy scales relate to each other.
Significance of the Research

Self-efficacy has been identified as a contributing factor for student academic outcomes and persistence (Fantz et al., 2011). There is a dearth in the contemporary literature of student self-efficacy within the field of engineering graphics. This study will contribute to the literature and field, research and analysis regarding current levels of student self-efficacy and the contribution of those levels on student academic outcomes. This study will also provide an empirical research base from which to discuss and study the impact of current practices on self-efficacy and refine instructional practices to best meet the needs of our current students and the changing demographics we will see over the next decade and beyond.

Limitations

The results of this study will be limited by several factors including:

1. Only one university will be included in the study;

2. The university is a large land-grant institution and generally admits students within the top ten percent of their high school graduating class, and

3. The limited body of prior research in this academic area necessitates the use of instruments with limited analysis from which to compare the results.

Definitions

Self-efficacy - a person’s confidence in his or her ability to muster the requisite intrinsic resources necessary for successful task completion (Bandura, 1997)
**Academic achievement** - a student’s ability to successfully complete academic tasks (Stajkovic & Luthans, 1998)

**Persistence** - successful completion of an academic degree program (Lent et al., 2015)
Chapter 2 Literature Review

In chapter one, the researcher stated that self-efficacy is a contributing factor for student academic outcomes and persistence. In this chapter, the researcher will present the literature supporting this contribution and situate self-efficacy research within engineering graphics education. This chapter addresses the extant literature related the following: the general construct of self-efficacy; measurement of self-efficacy; the relationship self-efficacy has with academic achievement, educational persistence, career persistence, educational attainment, and gender differences; self-efficacy as it relates to general engineering education and engineering graphics education.

Introduction

Self-efficacy is a mediating factor for the behavior of an individual, which in turn influences their performance (Bandura, 1977; Bandura, 1997). As a personal factor of social cognitive theory, self-efficacy refers to a person’s confidence in his or her ability to muster the requisite intrinsic resources necessary for successful task completion (Stajkovic & Luthans, 1998). The identification of self-efficacy as a personal factor within social cognitive theory is further supported by Bandura’s characterization and reference to self-efficacy as “people’s judgements of their capabilities…” (Bandura, 1986, p. 391) and those beliefs being central to the mechanism of personal agency (Lent, Brown, & Larkin, 1984; Wood & Bandura, 1989). Self-efficacy beliefs are recognized as having strong predictive validity with respect to achievement outcomes (Bandura, 1997; Pajares, 1996). These beliefs are also commonly understood to be domain and task specific (Blomquist, Farashah, & Thomas,
Within the construct of self-efficacy are four fundamental factors of: (a) experience or mastery experience; (b) modeling or vicarious experience; (c) social persuasion, and (d) physiological factors (Bandura, 1995).

**Theoretical Foundation**

**Social cognitive theory.** Bandura’s social cognitive theory explores the ways in which cognitive, behavioral, personal, and environmental factors interact and determine motivation and behavior (Crothers et al., 2008). Social cognitive theory suggests that parts of an individual’s knowledge acquisition are influenced by social interactions, social observation, outside influences (media, etc.), and experience (Bardach et al., 2010; Bandura, 1989c).

Behavior is frequently described as having unidirectional causation and described as being shaped and controlled by either environmental influences or behavioral dispositions (Bandura, 1989c). Social cognitive theory uses a model of triadic reciprocal determinism in which “behavior, cognition and other personal factors, and environmental influences all operate as interacting determinants that influence each other bidirectionally” (Bandura, 1989c, p. 2) (Figure 2.1). These factors do not necessarily have equal influence and one may exert greater influence on behavior and motivation and factors and influences may not occur concurrently (Bandura, 1989c).
Self-efficacy is identified as a personal factor of social cognitive theory and refers to a person’s confidence in his or her ability to muster the requisite intrinsic resources necessary for successful task completion (Stajkovic & Luthans, 1998). The identification of self-efficacy as a personal factor within social cognitive theory is further supported by Bandura’s characterization and reference to self-efficacy as “people’s judgements of their capabilities…” (Bandura, 1986, p. 391) and those beliefs being central to the mechanism of personal agency (Lent et al., 1994; Bandura 1989). Self-efficacy exists within the individual's internal locus of control (Bandura, 1977; Rotter, 1990).

**Self-efficacy, academic achievement, and persistence**. A student’s ability to successfully complete academic tasks is a direct result of their performance. This performance is mediated by the student’s confidence in his or her ability to summon the
needed cognitive, motivational, and actional resources for successful task completion within that specific context, or self-efficacy (Bandura, 1997; Stajkovic & Luthans, 1998). Self-efficacy is known to be domain and task specific and is not considered to apply to general topics and subjects, but rather, considerably more specific judgements about one’s capabilities (Linnenbrink & Pintrich, 2003). The specificity of self-efficacy measures is an important consideration as self-efficacy is a predictive factor for student performance (Zimmerman, 2000).

Zimmerman (2000) contends that self-efficacy beliefs correlate with domain-specific self-concepts; however, measurement of student levels of domain-specific self-concept beliefs do not have the same predictive validity as self-efficacy beliefs. For example, a domain-specific self-concept related to a general belief about competence such as understanding the engineering design process does not have the predictive ability of the self-efficacy belief related to evaluating and testing a design (Carberry, Lee, & Ohland, 2010).

Along with research supporting the mediation effect of self-efficacy beliefs on academic performance and goal attainment, these beliefs have been found to have this effect on attainment due to their influence on effort, persistence, and perseverance (Pajares, 1997a). Figure 2.2 displays a model for the influence of self-efficacy beliefs and outcome expectations on performance, persistence, and academic goal attainment within the context of triadic reciprocal determinism (Bandura, 1989) and the self-efficacy models described by Bandura (1977) and (Lent, Brown, & Hackett, 1994).
Figure 2.2. Self-efficacy and outcome expectation influence on performance, persistence, and academic goal attainment within the triadic reciprocal determinism framework.

Regardless of academic performance, students must remain in school and their academic programs to obtain degrees and be considered to have successfully completed a course of study. Their ability to persist through a university degree program is impacted by several factors including their levels of self-efficacy in the varied domains encountered in the normal course of a university degree program and its constituent courses. As one of these factors, self-efficacy is associated positively with persistence as well as academic performance (Fantz et al., 2011; Pajares, 1997b). The understanding and prediction of vocational choice, academic achievement, and other career-relevant behaviors are known contributions of individual’s level of self-efficacy (Multon, Brown, & Lent, 1991). As there is an abundance of evidence that self-efficacy is positively associated with educational attainment and persistence (Bandura, 1997), there is also significant evidence that self-
efficacy levels significantly impact the academic attainment levels for both male and female undergraduate students (Raelin et al., 2014).

**Self-Efficacy Measurement**

One focus, and a research question in this study is to investigate whether or not significant differences exist in students’ self-efficacy scores when a domain-specific scale and a general self-efficacy scale are used. Long standing beliefs and research trends have supported the findings that in order to have predictive validity, self-efficacy scales must be domain specific (Bandura, 2006; Lent et al., 1986; Zimmerman, 2000). Since the development of specific assessment scales for every conceivable domain may be problematic and require potentially thousands of valid and reliable to be created and disseminated, the ability to use a general scale may be more efficient. Assuming the prior research is correct, the predictive validity of a domain-specific scale will not be evident in the general self-efficacy scale. However, since the assessment is being given in both engineering graphics and educational domains, there may be an assumption by the students that it is related to engineering or engineering graphics. Moreover, there may be some contribution of the students’ academic self-efficacy toward their academic outcomes. If this is the case, there may be value in using both measures to gain a greater understanding of engineering graphics students self-efficacy as both engineers and students.

To this end, two self-efficacy assessments were chosen for this study. The first is a nine-question domain-specific three-dimensional modeling self-efficacy scale (adapted from Denson & Hill, 2010). This scale must be validated which is a fundamental component of
this research. Figure 2.3 provides the nine items in the assessment. These questions are answered using a seven-point Likert scale with one indicating “lowest agreement” and seven indicating “highest agreement.”

1. I feel that I am good at visualizing/manipulating 3-D objects in space.
2. I have confidence in my ability to model 3-D objects using computers.
3. I am confident enough in my 3-D modeling to help others model 3-D objects.
4. I am good at finding creative ways to model 3-D objects.
5. I believe I have the talent to do well in 3-D modeling.
6. I feel comfortable using 3-D modeling software.
7. I feel confident in my ability to create 3-D objects in a variety of ways.
8. I feel I can communicate 3-D objects to other peers.
9. I always understand what 3-D images are trying to communicate.

*Figure 2.3. The Three-Dimensional Modeling Self-Efficacy scale.*

The general self-efficacy scale used for this study is the Self-Efficacy for Learning (SEL) originally developed by (Klobas, Renzi, & Nigrelli, 2007). These questions are answered using a ten-point Likert scale with one indicating “I am definitely not able to do this” and ten indicating “I can definitely do this.” The SEL was found to have high internal consistency with Cronbach α levels ranging from .89 to .91 and included 22 items (Klobas et al., 2007). The SEL was also found to have a significant correlation to the expected score on an upcoming assessment. Although significant, there is no comparison to an actual grade or empirical course outcome. Klobas et al. (2007) also caution that the final version of the SEL needs to be further validated by other studies.

Ernst, Bowen, & Williams (2016) used the SEL to examine freshman engineering students determined to be at risk of not matriculating. When analyzed, the 22-item scale was determined to have high internal consistency with Cronbach’s α level of .94. The 22 items of the SEL are displayed in Figure 2.4.
1. I am able to organize my activities so that I can meet all course deadlines.
2. Soon after the end of a lesson, I am able to remember all of the key concepts.
3. I can understand all of the key concepts covered in my coursework.
4. I am able to explain to my fellow students, in a way they can understand, all of the key concepts covered in courses.
5. After sitting for an examination, I am able to remember all of the key concepts covered in courses.
6. When I find something new about a topic that I am studying, I am always able to connect it with other things that I know about the topic.
7. I always know how to get up to date on a topic if my knowledge of it is outdated.
8. Even when I haven’t participated in a lesson, I can always understand the concepts covered in the lesson by reading a textbook.
9. I am never embarrassed to ask a teacher for clarification.
10. I am always able to identify the most appropriate person to help me resolve a problem related to my study.
11. I am always able to evaluate the quality of fellow group members’ contributions when I participate in group activities.
12. I am always able to relate the notes I have made during a lesson with the topics covered in the course text or readings.
13. It is always easy for me to understand new information, even on a topic that does not interest me very much.
14. It is always easy for me to connect new information about a topic that interests me with other pieces of information.
15. During a course, if we are given a new task to complete, I can always complete it by applying the knowledge that I obtained from lessons.
16. Soon after the end of a lesson, I am always able to distinguish the most important concepts from concepts of less importance.
17. If, as part of a course, I participate in a forum or online discussion, I am always able to identify those messages which will improve my understanding of the material covered in the course.
18. I always find it easy to join a group of fellow students to study or complete course activities.
19. I am always able to use the library and library services to select appropriate books and articles for an assignment.
20. After a lesson, I am always able to integrate concepts described by the teacher with those presented in course texts and readings.
21. When I write an essay for a course, I am always able to incorporate knowledge gained from other sources.
22. I am always able to help other students solve problems based on concepts described in a lesson.

*Figure 2.4.* The Self-Efficacy for Learning scale (SEL) originally developed by Klobas, Renzi, & Nigrelli (2007).
Self-Efficacy in Engineering Education

Self-efficacy has also been shown to be positively associated with performance among introductory engineering graphics students (Metraglia, Villa, Baronio, & Adamini, 2016). Self-efficacy has been identified as having a significant impact on the educational outcomes and persistence in academic settings (Bandura, 1997; Lent et al., 1984; Pajares, 1996). Self-efficacy has also been shown to be a predictor of achievement and persistence among engineering students (Loo & Choy, 2013; M. K. Ponton, Edmister, Ukeiley, & Seiner, 2001). In addition to the positive relationship between self-efficacy beliefs and academic success and persistence generally, self-efficacy in engineering domains has been found to increase the self-efficacy beliefs of college engineering students significantly and, by extension, their choices to pursue and persist in engineering (Fantz et al., 2011).

There is a growing body of evidence that self-efficacy plays a significant role in predicting student outcomes and persistence in engineering education classes. In a pair of studies, (Lent, Brown, & Larkin, 1986) found associations between self-efficacy and academic outcomes. In the latter study, the use of hierarchical regression analysis suggested that self-efficacy beliefs contributed a significant amount of unique variance toward the prediction of student academic outcomes (Lent et al., 1986). In the 1986 study, two different self-efficacy scales were used with one being general and the other domain-specific. These two scales were not significantly intercorrelated supporting the contention that assessments be domain-specific and have clear construct validity (Bandura, 2006). Vogt, Hocevar, &
Hagedorn (2007) also confirmed previous research findings that self-efficacy levels are strongly associated with academic outcomes.

Lent’s work continued with a study in of 487 students in introductory engineering courses (Lent et al., 2005). The study findings were consistent with other research in that variable related to social cognitive theory such as self-efficacy are a high predictive factor for academic interests and goals in engineering. The study also used an academic self-efficacy instrument rather than a domain-specific scale. The use of a general scale with predictive outcomes for engineering students strengthens the rationale for this study comparing specific and general instruments.

Hutchison, Follman, Sumpter, & Bodner (2006) identified nine influential factors related to first-year engineering students’ self-efficacy beliefs. They also examined the students’ self-efficacy beliefs by gender. Understanding/learning was the greatest indicated factor contributing to self-efficacy in the study. This was followed by drive and motivation, teaming, computing ability, help, working assignments, problem-solving ability, enjoyment interest and satisfaction, and grades respectively. Only two factors held statistically significant differences between male and female students. Understanding/learning course material was indicated as influencing self-efficacy beliefs by 55 percent of male and 77 percent of female students ($p < .001$) and getting help was indicated by 38 percent of female students opposed to 19 percent of males ($p < .001$).

Hutchison et al. (2006) determined that eight of the nine above indicated factors of self-efficacy beliefs comport with the four sources of self-efficacy identified by Bandura.
Drive and motivation, or desire to succeed in the engineering course examined in the study, was not included as a contributor to self-efficacy in agreement with Bandura’s (1997) opinion that motivation biases the individual’s processing of efficacy information (Hutchison et al., 2006).

As with most studies, a 2011 study of an introductory design course confirmed self-efficacy as being associated with student achievement (Purzer, 2011). Purzer found that initial self-efficacy scores did not act as a predictive factor for academic outcomes at the end of the semester; however, end-of-semester scores were associated with gains in self-efficacy. Purzer uses these findings to suggest self-efficacy scores prior to an intervention do not share the predictive validity of the post-intervention assessment. This appears to run contrary to the extant literature and is limited by a small sample size (n = 22) and the single environment in which the study was conducted. Although potentially an outlier, this study does question if self-efficacy increases with learning and content knowledge and that content knowledge is the true cause for variance in academic outcomes rather than self-efficacy. The suggestion that self-efficacy is dependent on knowledge or cognitive ability has been frequently refuted and self-efficacy shown to be an independent contributing factor to performance (Maier & Curtin, 2005).

**Persistence.** Self-efficacy has been associated positively with persistence as well as academic performance (Fantz et al., 2011; Pajares, 1997b). Colleges and universities are seeing increasing undergraduate enrollment in science and engineering disciplines, but less that half of the graduates are entering the workforce in engineering (35%) and science (14%)
fields (National Science Board, 2016). Self-efficacy has been shown to significantly and positively associated with students’ intention to persist in engineering majors (Lent et al., 2015); however, entering the professional workforce after graduation may relate more to perceived value rather than self-efficacy (Mamaril et al., 2016). Although career persistence is of interest in engineering education, it is separate from the goals of this research. As there is an abundance of evidence that self-efficacy is positively associated with educational attainment and persistence (Bandura, 1997), determining if this association is present in engineering graphics is valuable to the field of engineering graphics education.

Lower levels of self-efficacy decrease the desire to persist in engineering especially in women (Godwin et al., 2016). There is also significant evidence that self-efficacy levels significantly impact the academic attainment levels for both male and female undergraduate students (Raelin et al., 2014). A better understanding of the factors related to both low and high self-efficacy levels may aid in identifying pedagogical and instructional methods to increase the levels of persistence in engineering and engineering graphics education.

**Gender differences.** Male students continue to dominate the classrooms and represent greater than 80% of graduates of undergraduate engineering degree programs (Godwin et al., 2016). Despite lower numbers, female students perform the same academically yet have lower levels of self-efficacy (Godwin et al., 2016).

There are conflicting findings when gender differences in engineering self-efficacy are examined. Hutchison et al. (2006) reported differences in some factors’ influencing males and females differently. The levels of self-efficacy were not reported as significantly
different. Similarly, no gender differences were reported by (Towle et al., 2005) among 219 engineering and science students in a study comparing self-efficacy beliefs to mental spatial rotation ability. Vogt et al. (2007) found significant differences in self-efficacy beliefs between male and female engineering students. This finding comports with the literature and previous findings in similar studies. They also found that their differences in the levels of influence self-efficacy have on other constructs associated with academic outcomes such as help-seeking, critical thinking, and effort with these factors being influenced at greater levels among female students. There is also evidence that the ways in which males’ and females’ self-efficacy beliefs are influenced by experiences (Hutchison-Green, Follman, & Bodner, 2008).

Although statistically significant differences in engineering self-efficacy were not found between males and females in a 2009 study, a statistically significant interaction between genders was indicated (Concannon & Barrow, 2009). This interaction was the result of women having significantly lower mean coping self-efficacy than their male counterparts. Concannon and Barrow (2009) point to the lack of statistically significant differences in mean engineering self-efficacy scores as confirmation of other studies similar findings including those of (Lent et al., 1986) and (Schaefers, Epperson, & Nauta, 1997). Concannon & Barrow (2009) directly repudiates (Bradburn, 1994) findings that female engineering majors have significantly lower levels of self-efficacy beliefs than males. Confirming these findings, (Buse, Bilimoria, & Perelli, 2013) found that female engineers who stay in the field expressed higher levels of self-efficacy than did those women who left engineering.
The identification and quantification of the self-efficacy beliefs of female engineering students may help to understand the gender differences in that context better. Self-efficacy has a clear impact on the academic persistence of female engineering students (Marra, Rodgers, Shen, & Bogue, 2012). Discovering trends in female students’ self-efficacy levels may serve to increase achievement and persistence within engineering graphics education. Currently, there is no data available for gender differences in self-efficacy within engineering graphics education. This research will add to the discussion and discourse into the gender differences in self-efficacy beliefs in engineering education.

**Mastery experiences in engineering education.** Bandura (1977) posited that mastery experience is a contributing factor to self-efficacy beliefs. Prior experience and success with engineering tasks contribute to students’ self-efficacy beliefs. This is confirmed in several studies that included prior engineering education courses and longitudinal studies of persistence in engineering (Amelink, Artis, & King Liu, 2015; Brown & Burnham, 2012; Carberry et al., 2010). Another study found that the only significant contribution external source of self-efficacy differences was whether or not students had a pre-engineering course and/or engineering related hobby (Fantz et al., 2011). Bandura’s prediction that successful task completion increases the mastery component and student self-efficacy by extension is demonstrated in the experiences of first-year engineering students (Hutchison-Green et al., 2008).

Because of the powerful influence of mastery on self-efficacy, some engineering programs are deliberately incorporating mastery experiences into course curricula and
programmatic changes (M. Ponton, 2002). These task mastery experiences add to the student’s self-efficacy beliefs making them more like to persevere when faced with more difficult tasks and potentially increase their academic persistence and matriculation.

**Summary**

Engineering education does have a growing body of literature in engineering self-efficacy. This research continues to confirm the positive association of self-efficacy with student academic outcomes. Mamaril, Usher, Li, Economy, & Kennedy (2016) validate prior assertions of the predictive validity of self-efficacy in engineering education. With a sample of 728 students, Mamaril and her colleagues found that engineering self-efficacy was the only significant predictor of core engineering GPA and explained as much as 56% of the variance explained by all of the predictors in the study. When specific engineering major course grades were isolated, 78% of the variance explained by predictors was accounted for by the student’s general engineering self-efficacy (Mamaril et al., 2016).
Chapter 3

Methodology

The purpose of this study is to examine and evaluate two measures of self-efficacy, self-efficacy of learning and self-efficacy in engineering graphics, to determine if a domain-specific assessment is needed or if a general assessment can be used as well as determine the contribution of self-efficacy toward student academic achievement in an introductory engineering graphics course. Additionally, what, if any, differences in self-efficacy exist among differing demographics groups within the course (e.g. gender, ethnicity, and major/minor).

A quantitative research approach was selected for this study utilizing a survey for data collection. This chapter will outline the steps that will be taken to perform this investigation. This study begins with validity and reliability analysis of two distinct self-efficacy instruments given to introductory engineering graphics students. This is followed by an exploratory factor analysis to determine any underlying structure for the survey results and concludes with a multiple regression analysis to determine what, if any, contribution to student achievement the results of the surveys demonstrates. Figure 3.1 displays this process.

*Figure 3.1. Analytical process used in this study.*
Exploratory factor analysis (EFA) was selected for this study as a statistical technique used to explore the underlying factor structure that exists within an observed set of variables (Burton & Mazerolle, 2011). EFA is used as a means to examine the underlying structure of an assessment and eliminate assessment items that correlate poorly with the desired factor, in this case, self-efficacy (Burton & Mazerolle, 2011; Furr & Bacharach, 2013). For this study, the goal is to understand the attributes related to self-efficacy as they relate to academic outcomes in an introductory engineering graphics course. Factor analysis is not a new method by which researchers and psychometricians evaluate and refine instruments, but until recent computing advances have allowed widespread ease of use and access, the use of the method was limited to time on a supercomputer or tedious hand calculation (Osborne, 2015). The use of factor analysis has seen a recent increase in use in engineering education (Mamaril, et al., 2016), self-efficacy in engineering education (Carberry et al., 2010), and in within engineering graphics (Ernst, Williams, Clark, & Kelly, 2015).

Methods
This study examines the psychometric properties of a 3D modeling assessment used in an introductory engineering graphics course at a large land-grant university in the southeastern United States. To guide this study, the following research questions were asked:

RQ1. Is there evidence that the domain-specific Three-Dimensional Modeling Self-Efficacy scale reliable?

RQ2. Is there evidence of validity in the domain-specific Three-Dimensional Modeling Self-Efficacy scale?
RQ3. What effect does a student’s three-dimensional modeling self-efficacy have on their academic outcomes in an undergraduate introductory engineering graphics course?

RQ4. To what extent do the results and contributions of the general self-efficacy of learning and domain-specific 3D modeling self-efficacy scales relate to each other.

Figure 3.2 contains the nine-item 3D modeling self-efficacy scale that was used in this study and a screenshot of a question from the electronic survey used in this study. These items address a student’s 3D modeling self-efficacy. The assessment asks students to indicate their level of agreement with the statements by writing down a number between one and seven with one indicating a low level of agreement and seven indicating a high level of agreement.

1. I feel that I am good at visualizing/manipulating 3D objects in space.
2. I have confidence in my ability to model 3D objects using computers.
3. I am confident enough in my 3D modeling to help others model 3D objects.
4. I am good at finding creative ways to model 3D objects.
5. I believe I have the talent to do well in 3D modeling.
6. I feel comfortable using 3D modeling software.
7. I feel confident in my ability to create 3D objects in a variety of ways.
8. I feel I can communicate 3D objects to other peers.
9. I always understand what 3D images are trying to communicate.

**Figure 3.2.** The Three-Dimensional Modeling Self-Efficacy scale.
Figure 3.3 displays the general self-efficacy scale used for this study is the Self-Efficacy for Learning (SEL) developed by Klobas, Renzi, and Nigrelli (2007) and a screenshot of a question from the electronic survey used in this study. These questions are answered using a ten-point Likert scale with one indicating “I am definitely not able to do this” and ten indicating “I can definitely do this.”

1. I am able to organize my activities so that I can meet all course deadlines.
2. Soon after the end of a lesson, I am able to remember all of the key concepts.
3. I can understand all of the key concepts covered in my coursework.
4. I am able to explain to my fellow students, in a way they can understand, all of the key concepts covered in courses.
5. After sitting for an examination, I am able to remember all of the key concepts covered in courses.
6. When I find something new about a topic that I am studying, I am always able to connect it with other things that I know about the topic.
7. I always know how to get up to date on a topic if my knowledge of it is outdated.
8. Even when I haven’t participated in a lesson, I can always understand the concepts covered in the lesson by reading a textbook.
9. I am never embarrassed to ask a teacher for clarification.
10. I am always able to identify the most appropriate person to help me resolve a problem related to my study.
11. I am always able to evaluate the quality of fellow group members’ contributions when I participate in group activities.
12. I am always able to relate the notes I have made during a lesson with the topics covered in the course text or readings.
13. It is always easy for me to understand new information, even on a topic that does not interest me very much.
14. It is always easy for me to connect new information about a topic that interests me with other pieces of information.
15. During a course, if we are given a new task to complete, I can always complete it by applying the knowledge that I obtained from lessons.
16. Soon after the end of a lesson, I am always able to distinguish the most important concepts from concepts of less importance.
17. If, as part of a course, I participate in a forum or online discussion, I am always able to identify those messages which will improve my understanding of the material covered in the course.
18. I always find it easy to join a group of fellow students to study or complete course activities.
19. I am always able to use the library and library services to select appropriate books and articles for an assignment.
20. After a lesson, I am always able to integrate concepts described by the teacher with those presented in course texts and readings.
21. When I write an essay for a course, I am always able to incorporate knowledge gained from other sources.
22. I am always able to help other students solve problems based on concepts described in a lesson.
Participants and Setting

Participants in this study are undergraduate students at NC State University. These students are enrolled in an introductory engineering graphics course, Foundations of Graphics (GC 120). GC 120 is a large group instructional setting with five-six sections taught per semester with 40-60 students in each section. Students are primarily engineering majors, but the course is offered for general credit and as part of the College of Education's technology, engineering, and design education and graphics communications programs.

The assessments are part of a battery of assessments given near the end of the semester and delivered electronically. Institutional review board (IRB) approval was sought and granted for ongoing research with this population. The assessments used in this study were added to that IRB protocol and approved.

Reliability

Reliability, or internal consistency for the purposes of this study, is the degree to which scale items within an instrument are intercorrelated, providing evidence of a commonly related construct (Drost, 2011; Trochim, Donnelly, & Arora, 2015). Critical in determining the validity of an instrument; several methods exist to determine reliability.
(Tavakol & Dennick, 2011). The most common method for determining the internal consistency of an instrument is to determine the coefficient alpha, commonly referred to as Cronbach’s alpha (Cronbach, 1951; Drost, 2011). Cronbach’s alpha can be used to examine the unidimensionality of an instrument and, when coupled with factor analysis, can provide further evidence of a scale’s unidimensionality (Tavakol & Dennick, 2011).

For these reasons, Cronbach’s alpha was selected for this study to examine the reliability of the instruments used. The coefficient alpha will be computed using Stata 14. The literature is consistent in the recommended range for an acceptable alpha value. Values ranging from 0.70 to 0.95 are considered to be sufficient to consider an instrument reliable (Cunningham, Preacher, & Banaji, 2001; Drost, 2011; Tavakol & Dennick, 2011).

Instrument Validity

To address the second research question, whether or not the self-efficacy scales used in this study are valid, we first examined the items in the instrument to determine if the instrument has face validity. Face validity or the degree to which an instrument appears to measure the constructs the instrument purports to assess from the perspective of a participant or population (Weiner & Craighead, 2010). Although subjective and often viewed as a weak form of construct validity (Drost, 2011), face validity was included to support the assertion that the instrument is appropriate for measuring the construct of 3D modeling self-efficacy (Weiner & Craighead, 2010). Face validity relies on the likely opinion of the test taker rather than expert(s) opinion and differs from content validity in that is not a true assessment of the construct(s) measured (Furr & Bacharach, 2013). Face validity is ultimately a subjective
judgement of the researcher regarding instruments used in this study (Drost, 2011) and is used, in part, to differentiate between the domain-specific and non-domain-specific instruments used in this research.

To further evaluate the validity of the 3D modeling self-efficacy instrument, we examined whether the results suggest the existence of convergent and discriminant validity as subsets of construct validity (Drost, 2011). Convergent and discriminant validity are not suitable as individually as evidence of construct validity; however, in conjunction provide evidence to support the construct validity of an instrument (Drost, 2011; Furr & Bacharach, 2013). In accordance with the literature regarding this construct, convergent, and discriminant validity, the convergent and discriminant validity of both the 3D Modeling Self-efficacy and Self-efficacy for Learning instruments will be analyzed.

**Construct Validity**

Campbell and Fiske (1959) first proposed investigating the convergent and discriminant validity as a method of determining construct validity. This method, the multitrait-multimethod correlation matrix (MTMM), is the most common method of determining both the convergent and discriminant validity - and thereby, construct validity - of an instrument (Burton & Mazerolle, 2011; Campbell & Fiske, 1959; Drost, 2011; Furr & Bacharach, 2013; Shadish, Cook, & Campbell, 2002). The MTMM method also mitigates the common method variance (also known as irrelevant method variance or mono-operation bias) threat to construct validity (Drost, 2011; Furr & Bacharach, 2013; Shadish et al., 2002).
Convergent validity is defined as “The idea that two measures of the same thing should correlate with each other” (Shadish et al., 2002). In other words, how does the instrument being used converge on a given construct when compared to another instrument purported to measure the same construct (Furr & Bacharach, 2013; Trochim, Donnelly, & Arora, 2015). In this case, this is the statistical method that will be employed in this study as a means of comparing the latent constructs measured by two different instruments will be the primary means of content validity determination.

In contrast to convergent validity, discriminant validity is the degree to which an instrument does not correlate with another instrument purported to measure a conceptually different construct (Burton & Mazerolle, 2011; Furr & Bacharach, 2013). The procedure by which discriminant validity is determined is identical to the method used to determine convergent validity except an instrument known to measure a different construct is used (Burton & Mazerolle, 2011).

To determine the convergent and discriminant validity of the instruments used in this study, the following procedure will be followed. Using the statistical analysis software Stata 14, a structural equation model (SEM) will be developed to investigate the relationships between three latent variables. These variables represent the two assessments used in this study (3D Modeling Self-Efficacy and Self-Efficacy for Learning) and a third instrument that assesses student motivations in engineering graphics courses (Barr, 2012; Barr, 2013).

A correlated uniqueness model fit will be applied to the SEM in order to produce and analyze an MTMM (StataCorp, 2015). The creation of the MTMM allows for analysis of the
Exploratory Factor Analysis

Exploratory factor analysis (EFA) is a statistical technique used to explore the underlying factor structure that exists within an observed set of variables (Burton & Mazerolle, 2011). Ultimately, EFA is used as a means to not only examine the underlying
structure of an instrument, but to eliminate poorly correlated with the desired factor, reduce the number of items in the instrument, and create a parsimonious assessment that captures the desired construct or constructs (Burton & Mazerolle, 2011; Furr & Bacharach, 2013). For this study, the goal is not the reduction of items and the creation of a more concise set of instruments. Rather, the goal is to understand the attributes related to self-efficacy as they relate to academic outcomes in an introductory engineering graphics course. As such, EFA was chosen over principle component analysis (PCA) because PCA is desired more for its role in item reduction and factor extraction rather than an investigation of the underlying factor structure (Burton & Mazerolle, 2011).

**Requirements for Exploratory Factor Analysis**

Prior to conducting the EFA, the adequacy of the sampling must be evaluated. Firstly, the sample size must be adequate. The literature recommends a minimum of 300 participants and the ratio of respondents to variables should be 10:1; however, smaller sample sizes are acceptable if the factor loadings scores are greater than .80 (Yong & Pearce, 2013). Next, the sampling adequacy must be assessed to determine if the inter-item correlations are suitable for EFA (Burton & Mazerolle, 2011). An examination of the instruments’ correlation matrix can be performed to ensure that the correlation matrix is not an identity matrix and that all items correlate with at least one other item with an \( r \) if at least .30 (Burton & Mazerolle, 2011; Yong & Pearce, 2013). Alternatively, sampling adequacy can be assessed using the Kaiser-Meyer-Olkin (KMO) correlation. KMO correlation values above .60 are regarded as sufficient to continue with an EFA (Burton & Mazerolle, 2011). Similarly, the examination
of the correlation matrix for inter-item correlation can be performed using Bartlett’s test of sphericity. Bartlett’s test of sphericity produces a chi-square output that, if significant, indicates the correlation matrix is not an identity matrix in which all the elements of the principal diagonal are ones and all other elements are zeros (Burton & Mazerolle, 2011). If Bartlett’s test of sphericity and the KMO correlation results indicate sampling adequacy and the lack of an identity matrix, the EFA can be performed on the data. Because of the objectivity of Bartlett’s test of sphericity and KMO correlations rather than “eyeballing” the correlation matrix, Stata 14 will be used to conduct these two tests to determine the appropriateness of the data for EFA.

**Factor Rotational Method**

Once the data are determined suitable for EFA, a factor rotational method must be selected. The two most common options for factor rotation are orthogonal and oblique rotation and are chosen based on what relationship is expected between potentially discovered factors or dimensions. Orthogonal rotation is used when no association between factors is expected whereas oblique rotation is used when there is an expected association between dimensions (Burton & Mazerolle, 2011; Furr & Bacharach, 2013). Narrowly, the instruments used in this study measure self-efficacy; broadly speaking, they measure self-efficacy as a mediating factor for student outcomes. With this in mind, oblique rotation was selected as the expectation is an association between underlying constructs.
**Determination of Factors**

Several considerations are present in the decision as to which factors to retain to investigate the latent constructs in the instrument. Common methods for identification of factors to retain include *Kaiser’s criterion*, scree test, *a priori* knowledge, total variance extracted, and parallel analysis (Burton & Mazerolle, 2011; Furr & Bacharach, 2013; Yong & Pearce, 2013). There is no “better” method of factor retention determination, and it has been described as being more art than science with the triangulation of several methods of analysis being common practice (Yong & Pearce, 2013).

The researchers *a priori* knowledge of the instruments, constructs of interest, and the context in which the study was conducted are an important factor in the analysis of the factor loadings and determining which factors to retain. *Kaiser’s criterion*, which recommends factors with eigenvalues greater than 1.00 are retained, is the most common method of determining factor retention (Burton & Mazerolle, 2011; Yong & Pearce, 2013). The scree test (analysis of the scree plot), so named as an analogy to rocks and boulders stacking up at the bottom of a cliff, is a graphical method of factor retention analysis and is comprised of the eigenvalues plotted on an x-y axis (Yong & Pearce, 2013). The point in the scree plot where the vertical component of the curve straightens out and becomes horizontal is referred to as the “elbow” and all factors at or before that point should be retained (Yong & Pearce, 2013). An inspection of the total variance extracted column in the factor output table can also be used to guide factor retention decisions. The cumulative variance extracted by each factor is evaluated until a suitable percentage of the variance in the model is accounted for (Beavers...
et al., 2013). The total variance accounted for should be greater than 75 percent, however, as low as 50 percent can be acceptable (Beavers et al., 2013).

Described by some as the most accurate method of determining factor retention, parallel analysis (PA) is the final method discussed in this study. In PA, random correlation matrices are generated and those computed random average eigenvalues are compared to their respective eigenvalues from the actual correlation matrix (Hayton, Allen, & Scarpello, 2004). Factors in which the actual eigenvalues that are greater than the parallel average random eigenvalues should be retained (Hayton et al., 2004).

Since no “best” method exists, it is incumbent on the researcher to carefully consider these methods and use their understanding of the theory underpinning the study to determine how to analyze the data and steps in the EFA best. For the EFAs performed in this study, the method(s) for factor retention will be determined when the actual, rather than theoretical, analysis is performed.

**Item Retention and Removal**

As stated previously, the goal of EFA is often the reduction of items in an instrument to remove irrelevant, redundant, and/or poorly loaded items resulting in a more parsimonious instrument that better measures the construct of interest (Furr & Bacharach, 2013). The reduction of the instruments for future use is outside the scope of this study; however, identifying the items from the two self-efficacy scales that most effectively and efficiently encapsulate the self-efficacy of the students’ participating in this study is an important facet of this research. As with factor retention, the researcher's judgement is an important
component in deciding which items to retain. Using the framework described by Yong and Pearce (2013), items will be considered for removal if their factor loadings are less than .30. If the factor loadings are greater than .50, retention will be considered for those that best fit the factor conceptually (Yong & Pearce, 2013). Items with cross-loading greater than .50 on multiple factors will be scrutinized and considered for removal (Yong & Pearce, 2013).

As this study involves the use of two separate instruments, the steps detailed above will have to be performed on both instruments. After the items are evaluated, and reduced if deemed necessary, the descriptive statistics for each adjusted assessment will be recalculated for comparison to the student outcome indicators and with each other to determine the extent to covariance between the two instruments.

**Self-Efficacy Assessment Comparison**

This study seeks to examine whether a domain-specific 3D modeling self-efficacy instrument will yield significantly different results when compared to a general self-efficacy of learning assessment given in the same context and what effect these two self-efficacy constructs contribute to student academic outcomes. The mean scores of these assessments will be compared to each other using a t-test to assess whether the mean scores of the two assessments are statistically different from each other (Trochim, Donnelly, & Arora, 2015).

To determine the impact of the constructs measured by the two assessments, a multiple regression analysis will be employed. Multiple regression analysis is used to examine the relationship between several independent or predictor variables and a dependent or criterion variable (Trochim et al., 2015). For this study, the participants’ mean scores on
the two self-efficacy instruments are the predictor (independent) variables used in the analysis with the final course, project, and exam grades as the criterion (dependent) variables. Independent analyses will be conducted to determine the extent of the relationship between 3D modeling self-efficacy and self-efficacy for learning and student academic outcomes with the assumption that the self-efficacy measures correlate significantly with the outcome measures (CITE).

**Summary**

The methods detailed in this chapter will allow for a comprehensive analysis of a factor (self-efficacy) known to be associated with academic outcomes. This research involves the validation of two distinct, but related instruments designed to measure two different aspects of self-efficacy among introductory engineering graphics students. After determining the instruments to be valid and reliable, the composite scores are calculated and used for investigating the extent to which the constructs measured contribute to the academic outcomes of participating student using multiple regression analysis.
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Chapter 4

Psychometric Properties and Demographic Analysis of a Three-Dimensional Modeling Self-Efficacy Instrument among Middle and High School Students

Introduction

Engineering graphics is a required area of study for many engineering programs and courses in the discipline have some of the highest enrollment in science, technology, engineering, and mathematics (STEM) education (Sadowski & Sorby, 2013). Although not specifically engineering, literacy in engineering graphics communication is necessary for success in engineering professions and will continue to be the preferred method for the communication of designs and ideas among engineering professionals (Barr, 2013; Branoff, Hartman, & Wiebe, 2002).

Middle and high school STEM courses are seeing increased use of computer-aided design (CAD) software (a central component of engineering graphics education) to enhance instruction and to incorporate 21st-century skills in the classroom (Katsioloudis & Jones, 2015; Schoembs, 2016). Engineering curricula such as Project Lead the Way (PLTW) and Engineering by Design (EbD) both explicitly use CAD as part of their courses and the inclusion of engineering skills and concepts in the Next Generation Science Standards (NGSS) will only increase the need for students to be at least exposed to CAD in the classroom. The use of CAD software has been a staple in technology and engineering courses for quite some time; moreover, CAD is now being used in math and science classes as well (Schoembs, 2016; Standish, Christensen, Knezek, Kjellstrom, & Bredder, 2016). The
growing number of Maker spaces and Fablabs in K-12 schools also adds to the need for students to have at least a basic understanding of CAD software as 3D fabrication technologies become more popular and common.

The availability of CAD software has increased as well. Web-based software such as Tinkercad and Onshape provide free CAD access on any computer. Programs such as SketchUp can be used free with some limitations whereas full version access to the industry-standard Autodesk suite of CAD programs are available to students and teachers. The growing prevalence of, and access to, CAD software in K-12 classrooms warrants study into factors that impact student learning and success.

**Theoretical Framework**

Self-efficacy, a person’s confidence in his or her ability to muster the requisite intrinsic resources necessary for successful task completion (Stajkovic & Luthans, 1998), is a known mediating factor of behavior that, in turn, influences the academic performance of a student (Bandura, 1997; Lent, Brown, & Larkin, 1984). Along with research supporting the mediation effect of self-efficacy beliefs on academic performance and goal attainment, researchers have found self-efficacy also mediates academic effort, persistence, and perseverance (Loo & Choy, 2013; Pajares, 1997). Self-efficacy is rooted in Social Cognitive Theory, whereby theorists and researchers contend that knowledge acquisition directly relates to observing others within their context of social interactions, experiences, and outside media influences (Bandura, 1997). Self-efficacy is also of importance due to its ability to be
a powerful contributor to students’ decision to choose a career in the STEM fields, as well as a predictor of success in these fields (Zeldin, Britner, & Pajares, 2008).

In addition to the positive relationship between self-efficacy beliefs and academic success and persistence generally, self-efficacy beliefs in engineering domains significantly influence engineering students’ choices to pursue and persist in engineering (Fantz, Siller, & Demiranda, 2011). However, research has consistently supported the assertion that to be an adequate predictor of student performance, self-efficacy scales must be domain specific (Bandura, 2006; Lent, Brown, & Hackett, 1994).

With domain specificity in mind, several engineering self-efficacy instruments have been developed (Fantz et al., 2011; Jones, Paretti, Hein, & Knott, 2010; Marra, Rodgers, Shen, & Bogue, 2009). However, researchers have not yet created and validated an instrument specifically related to engineering graphics. In this study, we examine the reliability, validity, and underlying factor structure of a self-efficacy scale specific to the domain of engineering graphics.

**Research Questions**

Toward a goal of increasing persistence and participation in engineering, this research is focused on the continued development and validation of a self-efficacy instrument to measure the self-efficacy related to students’ three-dimensional modeling abilities. The following questions guided this research:

**RQ1.** Is the domain-specific Three-Dimensional Modeling Self-Efficacy scale reliable?
RQ2. Is the domain-specific Three-Dimensional Modeling Self-Efficacy scale valid?

RQ3. What is/are the underlying latent constructs for the items in the domain-specific Three-Dimensional Modeling Self-Efficacy scale?

RQ4. What, if any, significant differences in self-efficacy levels exist between male and female students and between middle and high school students.

Methods

**Instrument development.** Currently, an instrument available that measures students’ self-efficacy as it relates to three-dimensional modeling does not exist. Bandura (2006) argued that “there is not an all-purpose measure of perceived self-efficacy” (p. 307) and Sherer et al. (1982) offered that self-efficacy is a task-specific belief. Therefore, to measure self-efficacy effectively as it relates to three-dimensional modeling, a scale specifically related to this domain must be developed.

The Three-Dimensional Modeling Self-Efficacy scale used in this study was developed by modifying and building upon instruments used in prior studies. Development of the Three-Dimensional Modeling Self-Efficacy scale began with the modification and building upon instruments used in prior studies and grounded in the work of Bandura, especially his *Guide for Constructing Self-Efficacy Scales* (2006). The format of the instrument used in this study closely resembles the evaluation survey created by The New Traditions Project (Denson & Hill, 2010).
It was necessary to modify the scale items to relate specifically to the modeling of three-dimensional objects, the domain measured by this instrument. Researchers collaborated with subject matter experts (SME) in graphics communication at a large, land-grant institution to confirm the existing items were associated with engineering graphics. The SMEs provided comments and feedback, which the researchers incorporated into the scale design. The SMEs and researchers agreed the resulting instrument measured the desired domain of three-dimensional modeling that framed this particular study and had face validity, which is defined as the degree to which an instrument appears to measure the constructs the instrument purports to assess from the perspective of a participant (Weiner & Craighead, 2010). Figure 4.1 displays the nine-item Three-Dimensional Modeling Self-Efficacy scale developed for and used in, this study. Each item uses a seven-point Likert-type scale from “highest level of agreement” to “lowest level of agreement.”

1. I feel that I am good at visualizing/manipulating 3D objects in space.
2. I have confidence in my ability to model 3D objects using computers.
3. I am confident enough in my 3D modeling to help others model 3D objects.
4. I am good at finding creative ways to model 3D objects.
5. I believe I have the talent to do well in 3D modeling.
6. I feel comfortable using 3D modeling software.
7. I feel confident in my ability to create 3D objects in a variety of ways.
8. I feel I can communicate 3D objects to other peers.
9. I always understand what 3D images are trying to communicate.

*Figure 4.1.* The Three-Dimensional Modeling Self-Efficacy scale.

**Participants.** This study was conducted during a STEM summer camp at a large, southeastern land-grant university. Ninety-one middle and high school students participating in the summer camp took the survey at the end of their weeklong experience. Males represent
approximately 63% of the sample population (n = 57) and females representing 37% (n = 34). Middle school students represent approximately 47% of the sample population (n = 41) and high school students representing 53% (n = 47); three participants left their grade level blank on the survey.

**Reliability.** Reliability, or internal consistency, is the degree to which scale items within an instrument are intercorrelated, providing evidence of a commonly related construct (Trochim, Donnelly, & Arora, 2015). The most common method for determining the internal consistency of an instrument is to determine the coefficient alpha, commonly referred to as Cronbach's alpha (Drost, 2011). Cronbach’s alpha can be used to examine the unidimensionality of an instrument and, when coupled with factor analysis, can provide further evidence of a scale’s unidimensionality (Tavakol & Dennick, 2011). Values ranging from 0.70 to 0.95 are considered to be sufficient to consider an instrument reliable (Drost, 2011). For this study, an alpha of 0.70 was used as a minimum value to determine reliability.

**Validity.** To address the second research question, whether or not the self-efficacy scale used in this study is valid, the researcher first examined the items in the instrument to determine if the instrument had face validity. Face validity is the degree to which an instrument appears to measure the constructs the instrument purports to assess from the perspective of a participant (Weiner & Craighead, 2010). Face validity relies on the likely opinion of the test taker rather than expert(s) opinion and differs from content validity in that is not a true assessment of the construct(s) measured (Furr & Bacharach, 2013).
**Exploratory Factor Analysis.** Exploratory factor analysis (EFA) is a statistical technique used to explore the underlying factor structure that exists within an observed set of variables (Burton & Mazerolle, 2011). Ultimately, EFA is used as a means to not only examine the underlying structure of an instrument, but also to eliminate items poorly correlated with the desired factor, reduce the number of items in the instrument, and create a parsimonious assessment that captures the desired construct (Burton & Mazerolle, 2011).

**Requirements for exploratory factor analysis.** Prior to conducting the EFA, the researcher evaluated the adequacy of the sample. First, the sample size must be adequate. There are varying opinions in the extant literature on the appropriate sample size required for EFA. There is general acceptance that 100 is the recommended minimum sample size; however, there is evidence that EFA can yield reliable results with a sample as low as 50 for measures of social constructs provided the number of factors is low (de Winter, Dodou, & Wieringa, 2009). The literature also contends that a ratio of respondents to variables should be 10:1 (Yong & Pearce, 2013). Provided these factors, the researcher believes the sample in this case (n = 91) is adequate.

Next, the researcher assessed the sampling adequacy to determine if the inter-item correlations are suitable for EFA (Burton & Mazerolle, 2011). An examination of the instruments correlation matrix was performed to ensure that the correlation matrix is not an identity matrix and that all items correlate with at least one other item with a correlation coefficient of at least .30 (Burton & Mazerolle, 2011). Sampling adequacy was also assessed using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. KMO correlation
values above .60 are regarded as sufficient to continue with an EFA (Burton & Mazerolle, 2011). Similarly, the examination of the correlation matrix for inter-item correlation can be performed using Bartlett’s test of sphericity. Bartlett’s test of sphericity produces a chi-square output that, if significant, indicates the correlation matrix is not an identity matrix (Burton & Mazerolle, 2011). If Bartlett’s test of sphericity and the KMO correlation results indicate sampling adequacy and the lack of an identity matrix, the EFA can be performed on the data.

**Determination of factors.** Kaiser’s criterion, which recommends factors with eigenvalues greater than 1.00 be retained, is the most common method in determining factor retention (Burton & Mazerolle, 2011; Yong & Pearce, 2013) and was used in this study. The researcher also conducted an inspection of the total variance extracted column in the factor output table which can also be used to guide factor retention decisions. The cumulative variance extracted by each factor was evaluated until 75% of the variance in the model was accounted (Beavers et al., 2013). Since no “best” method exists, it was incumbent upon on the researcher to carefully consider these methods and use their *a priori* understanding of the theory underpinning this study to determine how to best analyze the data and steps in the EFA.

**Item retention and removal.** The goal of EFA is often the reduction of items in an instrument to remove irrelevant, redundant, and/or poorly loaded items resulting in a more parsimonious instrument that better measures the construct of interest (Furr & Bacharach, 2013). Items were considered for removal if their factor loadings are less than .40.
The researcher analyzed differences in the three-dimensional modeling self-efficacy levels between male and female students and those students in middle or high school. These comparisons were made using analysis of variance (ANOVA). The researcher also looked for significant correlations between levels of three-dimensional modeling self-efficacy and gender and grade level.

**Findings**

Descriptive statistics and tests for normality (skewness and kurtosis) are displayed in Table 4.1. Stata 14 was used to analyze the data in this study.

**Table 4.1**

Descriptive statistics and tests for normality for the three-dimensional modeling self-efficacy scale

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
<th>Skewness</th>
<th>Kurtosis</th>
<th>chi2</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.85</td>
<td>1.52</td>
<td>.01</td>
<td>.95</td>
<td>6.60</td>
<td>0.037</td>
</tr>
<tr>
<td>2</td>
<td>4.66</td>
<td>1.68</td>
<td>.29</td>
<td>.00</td>
<td>11.73</td>
<td>0.003</td>
</tr>
<tr>
<td>3</td>
<td>4.15</td>
<td>1.58</td>
<td>.57</td>
<td>.12</td>
<td>2.87</td>
<td>0.238</td>
</tr>
<tr>
<td>4</td>
<td>4.68</td>
<td>1.73</td>
<td>.35</td>
<td>.00</td>
<td>8.54</td>
<td>0.014</td>
</tr>
<tr>
<td>5</td>
<td>5.23</td>
<td>1.47</td>
<td>.00</td>
<td>.30</td>
<td>9.54</td>
<td>0.009</td>
</tr>
<tr>
<td>6</td>
<td>4.48</td>
<td>1.82</td>
<td>.43</td>
<td>.00</td>
<td>11.02</td>
<td>0.004</td>
</tr>
<tr>
<td>7</td>
<td>4.59</td>
<td>1.59</td>
<td>.10</td>
<td>.10</td>
<td>5.34</td>
<td>0.069</td>
</tr>
<tr>
<td>8</td>
<td>4.40</td>
<td>1.74</td>
<td>.11</td>
<td>.03</td>
<td>6.55</td>
<td>0.038</td>
</tr>
<tr>
<td>9</td>
<td>4.73</td>
<td>1.70</td>
<td>.01</td>
<td>.86</td>
<td>7.05</td>
<td>0.030</td>
</tr>
</tbody>
</table>

*Note.* Values in bold are significant at $p < .05$ level.
Reliability. The reliability of the Three-Dimensional Modeling Self-Efficacy scale was determined using Cronbach’s alpha statistic to address our first research question. The researcher determined the nine-item Three-Dimensional Modeling Self-Efficacy scale to be reliable ($\alpha = .81$) based on the stated threshold of .70 (Drost, 2011) with an average inter-item covariance of .87.

Validity. As noted previously, the researcher first determined whether the Three-Dimensional Modeling Self-Efficacy scale had face validity. Although subjective and often viewed as a weak form of construct validity (Drost, 2011), face validity was included to support the assertion that the instrument is appropriate for measuring the construct of three-dimensional modeling self-efficacy (Weiner & Craighead, 2010).

Exploratory Factor Analysis. Factorability. Toward investigating the underlying factor structure of the Three-Dimensional Modeling Self-Efficacy scale and addressing our third research question, the researcher conducted an exploratory factor analysis. The initial step in EFA is to determine the adequacy of the sample. To accomplish this, the researcher used three methods of analysis: examination of the correlation matrix, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, and Bartlett’s test of sphericity. Table 4.2 displays the correlation matrix. Analysis of the correlations revealed that all nine items significantly correlated with at least one other item with a minimum coefficient of .30 (Burton & Mazerolle, 2011).
Table 4.2

Intercorrelations for Items in the 3D Modeling Self-Efficacy Scale

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.38</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>.33</td>
<td>.49</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>.21</td>
<td>.20</td>
<td>.33</td>
<td>-</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>5</td>
<td>.22</td>
<td>.22</td>
<td>.24</td>
<td>.39</td>
<td>-</td>
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<td></td>
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<tr>
<td>6</td>
<td>.37</td>
<td>.63</td>
<td>.40</td>
<td>.16</td>
<td>.32</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>.41</td>
<td>.45</td>
<td>.43</td>
<td>.41</td>
<td>.41</td>
<td>.53</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>.32</td>
<td>.27</td>
<td>.40</td>
<td>.40</td>
<td>.31</td>
<td>.23</td>
<td>.50</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>.27</td>
<td>.07</td>
<td>.24</td>
<td>.30</td>
<td>.18</td>
<td>.07</td>
<td>.11</td>
<td>.39</td>
<td>-</td>
</tr>
</tbody>
</table>

Note. Coefficients in bold are significant at \( p < .05 \) level.

An examination of the Kaiser-Meyer-Olkin measure of sampling adequacy suggested the sample was adequate for factoring (KMO = .80) and Bartlett’s test of sphericity was significant (\( \chi^2 (36) = 233.452, p < .001 \)) indicating the sample was not an identity matrix. These two measures, combined with the analysis of the correlation matrix, support our contention that the sample is factorable (Burton & Mazerolle, 2011).

**Factor determination.** Once the factorability of the sample was determined, an EFA was conducted to determine the number of factors underlying the Three-Dimensional Modeling Self-Efficacy scale. The results of the EFA for the nine-item scale can be found in Table 4.3.
Table 4.3

Factor Loadings from Exploratory Factor Analysis: Uniqueness, Eigenvalues, and Percentages of Variance for the Three-Dimensional Modeling Self-Efficacy scale (9-Item)

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor loading</th>
<th>Communality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>.54</td>
<td>-.03</td>
</tr>
<tr>
<td>2</td>
<td>.64</td>
<td>-.38</td>
</tr>
<tr>
<td>3</td>
<td>.62</td>
<td>-.03</td>
</tr>
<tr>
<td>4</td>
<td>.51</td>
<td>.34</td>
</tr>
<tr>
<td>5</td>
<td>.49</td>
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<tr>
<td>6</td>
<td>.65</td>
<td>-.41</td>
</tr>
<tr>
<td>7</td>
<td>.74</td>
<td>-.04</td>
</tr>
<tr>
<td>8</td>
<td>.61</td>
<td>.32</td>
</tr>
<tr>
<td>9</td>
<td>.34</td>
<td>.39</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>3.05</td>
<td>.70</td>
</tr>
<tr>
<td>% of Variance</td>
<td>90.41</td>
<td>20.78</td>
</tr>
</tbody>
</table>

Using Kaiser’s criterion, factors with eigenvalues greater the 1.00 were retained (Yong & Pearce, 2013). To confirm this method, the researcher also examined the total variance explained. Factor one explains 90.41% of the variance in the sample; greater than the determination criteria of .75 (Beavers et al., 2013). Both methods suggest a single factor structure for the Three-Dimensional Modeling Self-Efficacy scale. The single factor solution is displayed in Table 4.4.
Table 4.4

Single Factor Loading from Exploratory Factor Analysis: Uniqueness, Eigenvalues, and Percentages of Variance for the Three-Dimensional Modeling Self-Efficacy scale (9-Item)

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor loading</th>
<th>Communality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.54</td>
<td>.29</td>
</tr>
<tr>
<td>2</td>
<td>.64</td>
<td>.41</td>
</tr>
<tr>
<td>3</td>
<td>.62</td>
<td>.39</td>
</tr>
<tr>
<td>4</td>
<td>.51</td>
<td>.26</td>
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<tr>
<td>5</td>
<td>.49</td>
<td>.24</td>
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<tr>
<td>6</td>
<td>.65</td>
<td>.42</td>
</tr>
<tr>
<td>7</td>
<td>.74</td>
<td>.55</td>
</tr>
<tr>
<td>8</td>
<td>.61</td>
<td>.37</td>
</tr>
<tr>
<td>9</td>
<td>.34</td>
<td>.11</td>
</tr>
<tr>
<td>Eigenvalue</td>
<td>3.05</td>
<td></td>
</tr>
<tr>
<td>% of Variance</td>
<td>90.41</td>
<td></td>
</tr>
</tbody>
</table>

*Item retention.* Analysis of the factor loadings of the scale items indicated that item nine had both a remarkably lower factor loading and communality values. As a result, the researcher examined the text of item nine (I always understand what 3D images are trying to communicate) and determined it related to the subject’s understanding rather than their belief in their ability to complete a task or “do.” Based on this and the low factor loading (< .40) and communality values of item nine, the researcher made the decision to remove the item from the Three-Dimensional Modeling Self-Efficacy scale (Furr & Bacharach, 2013).

*Eight-item scale.* To examine the psychometric properties of the eight-item Three-Dimensional Modeling Self-Efficacy scale, the researcher used the same methods and
analysis used for the nine-item scale. The researcher determined the eight-item Three-Dimensional Modeling Self-Efficacy scale to be reliable (α = .81) with a greater average inter-item covariance (.96) than the nine-item version (.87). Table 4.5 displays the single factor solution for the eight-item Three-Dimensional Modeling Self-Efficacy scale.

Table 4.5

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor loading</th>
<th>Uniqueness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.53</td>
<td>.72</td>
</tr>
<tr>
<td>2</td>
<td>.66</td>
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<td>3</td>
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<td>.61</td>
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<tr>
<td>4</td>
<td>.48</td>
<td>.76</td>
</tr>
<tr>
<td>5</td>
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<td>.76</td>
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<td>6</td>
<td>.67</td>
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<tr>
<td>7</td>
<td>.75</td>
<td>.43</td>
</tr>
<tr>
<td>8</td>
<td>.57</td>
<td>.67</td>
</tr>
<tr>
<td></td>
<td>Eigenvalue</td>
<td>2.92</td>
</tr>
<tr>
<td>% of Variance</td>
<td>98.26</td>
<td></td>
</tr>
</tbody>
</table>

The factor underlying the eight-item Three-Dimensional Modeling Self-Efficacy scale explains 98.26% of the variance. When compared to the nine-item scale, the shortened instrument demonstrates improved factor loading and communality values than does the nine-item version.
Demographic comparison. No significant correlation was found between the Three-Dimensional Modeling Self-Efficacy scale (eight-item) and the participant’s gender ($r = .13, p = .203$) nor between score and grade level ($r = -.03, p = .768$). Neither gender or grade level showed significant differences when compared using ANOVA, $F(2, 85) = 1.35, p = .265$. Thus, neither gender nor grade level represent a significant factor in participants’ three-dimensional modeling self-efficacy levels in this study.

Discussion

The analysis presented in this paper offers evidence toward the validity and reliability of the eight-item Three-Dimensional Modeling Self-Efficacy scale. The results also support the removal of item nine in the instrument resulting in an instrument that appears to better measure the construct of three-dimensional modeling self-efficacy and is slightly more parsimonious.

Of particular interest in the results of this study was the lack of difference in self-efficacy levels across demographics. Current research suggests that females in engineering generally have lower levels of self-efficacy than do males (Godwin et al., 2016). It should be noted that these trends are measured and discussed in college and career levels with older participants. The lack of difference may suggest that that the instrument is not sensitive enough or inappropriate for the age group in this study or that self-efficacy levels in female students diverges from males during secondary education. Both of these potential reasons require and should encourage further study and investigation. It is also possible that participants in this study (or the aggregate scores) represent outliers or other demographic
differences unknown to the researcher lead to these differences. Regardless, more study is needed with different populations.

An examination into the construct validity of the Three-Dimensional Modeling Self-Efficacy scale such as testing for the existence of convergent and discriminant validity are important aspects of instrument validation (Drost, 2011), but were not possible for this study given the time and access constraints provided to the researcher. This represents both a limitation and an area of further study for the development of the Three-Dimensional Modeling Self-Efficacy scale.

The eight-item Three-Dimensional Modeling Self-Efficacy scale is currently the only known instrument the specifically relates to engineering graphics education. More study is needed into the validity of the instrument and what other areas in addition to three-dimensional modeling can or should be added to the instrument to more completely measure students studying engineering graphics or CAD.
References


Chapter 5

Three-Dimensional Modeling Self-Efficacy: An Examination of Psychometric Properties toward Validation of a Domain-Specific Instrument in Engineering Graphics Education

Introduction

The four-year university retention rates for engineering majors in the same field in which they started is 55.9% (National Science Board, 2016). The same report also indicates that only 35% of those who graduate with engineering degrees enter the workforce in their field of study. With the President’s Council of Advisors on Science and Technology (PCAST) calling for an additional 1 million science, technology, engineering, and mathematics (STEM) professionals by 2022 to maintain our global status (Olson & Riordan, 2012), there is a demonstrable need to increase both postsecondary education retention rates and the number of engineering graduates entering the field.

The identification and deeper understanding of noncognitive factors that affect student retention and persistence is of particular import in undergraduate settings where students face increasingly challenging and unfamiliar tasks (Nagaoka et al., 2013). Numerous studies have linked non-cognitive factors to persistence in educational settings (Farrington et al., 2012; Gloria, Kurpius, Hamilton, & Willson, 1999; Nagaoka et al., 2013). Self-efficacy is one such non-cognitive factor that contributes to, among others, the persistence of students to continue in academic environments.
In this study, toward a goal of increasing persistence and participation in engineering, the focus is on the continued development and validation of a self-efficacy instrument to measure the self-efficacy related to students’ three-dimensional modeling abilities, a core competency in the field of engineering graphics.

**Contextualization**

Engineering graphics is a required area of study for many engineering programs and courses in the discipline have some of the highest enrollment in STEM education (Sadowski & Sorby, 2013). Although not specifically engineering, literacy in engineering graphics communication is necessary for success in engineering professions. Engineering education’s long history of utilizing graphics linguistically continues to be the preferred method for the communication of designs and ideas (Barr, 2013; Branoff, Hartman, & Wiebe, 2002). With the rise of computer use to near ubiquity in college coursework over the last quarter-century, three-dimensional modeling has become a central component in most engineering graphics programs and has become a hub for all engineering communication activities (Barr, 2004).

The Accreditation Board for Engineering and Technology (ABET) has, for the accreditation of engineering programs, a criterion that programs must have documentation of student abilities to communicate effectively – Criterion 3(g) – and a proposed change that adds “with a variety of audiences” (Accreditation Board for Engineering and Technology, (ABET), 2016). Despite there not being specific reference to engineering graphics, the preference for graphical communication in the broader engineering field generally and in many sub-disciplines (i.e., mechanical and civil engineering) places engineering education as
a foundational course within engineering curricula. As such, this research was conducted at a large public university with more than 10,000 undergraduate engineering students, many of whom are required to take at least an introductory engineering graphics course.

**Theoretical Framework**

Identified as a personal factor of social cognitive theory, self-efficacy refers to a person’s confidence in his or her ability to muster the requisite intrinsic resources necessary for successful task completion (Stajkovic & Luthans, 1998). The identification of self-efficacy as a personal factor within social cognitive theory is further supported by Bandura’s characterization and reference to self-efficacy as “people’s judgements of their capabilities…” (Bandura, 1986, p. 391) and those beliefs being central to the mechanism of personal agency (Bandura, 1989; Lent, Brown, & Hackett, 1994). Self-efficacy exists within the individual's internal locus of control (Rotter, 1966).

Self-efficacy is a known mediating factor of behavior that, in turn, influences the academic performance of a student (Lent, Brown, & Larkin, 1984). Along with research supporting the mediation effect of self-efficacy beliefs on academic performance and goal attainment, researchers have found self-efficacy also mediates academic effort, persistence, and perseverance (Pajares, 1997). Self-efficacy has also been shown to be positively associated with performance among introductory engineering graphics students (Metraglia, Baronio, & Villa, 2015; Metraglia, Villa, Baronio, & Adamini, 2016)

A student’s ability to successfully complete academic tasks is a direct result of their performance. This performance is mediated by the student’s confidence about his or her
ability to summon the needed cognitive, motivational, and actional resources for successful task completion within that specific context, or self-efficacy (Bandura, 1997; Stajkovic & Luthans, 1998). Self-efficacy is known to be domain and task specific and is not considered to apply to general topics and subjects, but rather, considerably more specific judgements about one’s capabilities (Linnenbrink & Pintrich, 2003). The specificity of self-efficacy measures is an important consideration as self-efficacy is a predictive factor for student performance (Zimmerman, 2000).

Zimmerman (2000) contends that self-efficacy beliefs correlate with domain-specific self-concepts; however, measurement of student levels of domain-specific self-concept beliefs do not have the same predictive validity as self-efficacy beliefs. For example, a domain-specific self-concept related to a general belief about competence such as understanding the engineering design process does not have the predictive ability of the self-efficacy belief related to evaluating and testing a design (Carberry, Lee, & Ohland, 2010).

Along with research supporting the mediation effect of self-efficacy beliefs on academic performance and goal attainment, these beliefs have been found to have this effect on attainment due to their influence on effort, persistence, and perseverance (Pajares, 1997). Figure 5.1 displays a model for the influence of self-efficacy beliefs and outcome expectations on performance, persistence, and academic goal attainment within the context of triadic reciprocal determinism (Bandura, 1989) and the self-efficacy models described by Bandura (1977) and (Lent, Brown, & Hackett, 1994). Triadic reciprocal determinism is defined as “behavior, cognition and other personal factors, and environmental influences all
operate as interacting determinants that influence each other bidirectionally” (Bandura, 1989, p. 2) (Figure 5.1). These factors do not necessarily have equal influence and one may exert greater influence on behavior and motivation and factors and influences may not occur concurrently (Bandura, 1989).

*Figure 5.1. Self-efficacy and Outcome Expectation Influence on Performance, Persistence, and Academic Goal Attainment within the Triadic Reciprocal Determinism Framework.*

Regardless of academic performance, students must remain in both school and their academic programs to obtain degrees and be considered to have successfully completed a course of study. Their ability to persist through a university degree program is impacted by several factors including their levels of self-efficacy in the varied domains encountered in the normal course of a university degree program and its constituent courses. As one of these factors, self-efficacy is associated positively with persistence as well as academic performance (Fantz, Siller, & Demiranda, 2011; Pajares, 1997). The understanding and prediction of vocational choice, academic achievement, and other career-relevant behaviors
are known contributions to an individual’s level of self-efficacy (Multon, Brown, & Lent, 1991). As there is an abundance of evidence that self-efficacy is positively associated with educational attainment and persistence (Bandura, 1997), there is also significant evidence that self-efficacy levels significantly impact the academic attainment levels for both male and female undergraduate students (Raelin et al., 2014).

**Self-Efficacy in Engineering Education**

Self-efficacy has been shown to be positively associated with performance among introductory engineering graphics students (Metraglia, Villa, Baronio, & Adamini, 2016), and as having a significant impact on the educational outcomes and persistence in academic settings (Bandura, 1997; Lent et al., 1984; Pajares, 1996). Self-efficacy has also been identified as a predictor of achievement and persistence among engineering students (Loo & Choy, 2013; Ponton, Edmister, Ukeiley, & Seiner, 2001). In addition to the positive relationship between self-efficacy beliefs and academic success and persistence generally, self-efficacy in engineering domains is known to significantly increase the self-efficacy beliefs of college engineering students and, by extension, their choices to pursue and persist in engineering (Fantz, Siller, & Demiranda, 2011).

There is a growing body of evidence that self-efficacy plays a significant role in predicting student outcomes and persistence in engineering education classes. In a pair of studies, Lent, Brown, & Larkin, (1984; 1986) found associations between self-efficacy and academic outcomes. In the latter study, the use of hierarchical regression analysis suggested that self-efficacy beliefs contributed a significant amount of unique variance toward the
prediction of student academic outcomes (Lent et al., 1986). In the 1986 study, two different self-efficacy scales were used with one being general and the other being domain-specific. These two scales were not significantly intercorrelated supporting the contention that assessments be domain-specific and have clear construct validity (Bandura, 2006). Vogt, Hocevar, & Hagedorn (2007) also confirmed previous research findings that self-efficacy levels are strongly associated with academic outcomes.

This research continues to confirm the positive association between self-efficacy and student academic outcomes. Extant research continues to validate assertions of the predictive nature of self-efficacy in engineering education. With a sample of 728 students, Mamaril and her colleagues (2016) found that engineering self-efficacy was the only significant predictor of core engineering GPA and explained as much as 56% of the variance explained by all of the predictors in the study. When specific engineering major course grades were isolated, 78% of the variance explained by predictors was accounted for by the student’s general engineering self-efficacy levels.

**Research Questions**

At issue is the lack of domain-specific instrumentation to examine self-efficacy within the field of engineering graphics. To that end, this study builds on two previous investigations into the psychometric properties of a Three-Dimensional Modeling Self-Efficacy scale specific to a fundamental proficiency within the domain of engineering graphics (Author). The following questions guided this research:
RQ1. Is there evidence of reliability in the domain-specific Three-Dimensional Modeling Self-Efficacy scale?

RQ2. Is there evidence of validity in the domain-specific Three-Dimensional Modeling Self-Efficacy scale?

RQ3. What is/are the underlying latent constructs for the items in the domain-specific Three-Dimensional Modeling Self-Efficacy scale?

RQ4. What effect does a student’s Three-Dimensional Modeling Self-Efficacy have on their academic outcomes in an undergraduate introductory engineering graphics course?

Methods

Participants and setting. Participants in this study are undergraduate students at a large land-grant university in the southeastern United States. Participating students are enrolled in an introductory engineering graphics course. The course is taught in a large group instructional setting with 6 sections taught per semester and 40-60 students in each section. Students are primarily engineering majors, but the course is also offered for general credit and open to all students with no pre- or co-requisites. Table 5.1. displays the demographic characteristics of the 503 students who participated in this study over the course of three consecutive semesters. The instruments used in this study are part of a battery of assessments given near the end of the semester and completed electronically. Institutional review board (IRB) approval was sought and granted for research with this population.
Table 5.1

Demographic Characteristics of Participants (n = 503)

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gender</strong></td>
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<td></td>
</tr>
<tr>
<td>Male</td>
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<tr>
<td>Female</td>
<td>87</td>
<td>17.30%</td>
</tr>
<tr>
<td>Other gender identity</td>
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<td>0.20%</td>
</tr>
<tr>
<td>Prefer not to answer</td>
<td>7</td>
<td>1.39%</td>
</tr>
<tr>
<td><strong>Race/Ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>American Indian or Alaska Native</td>
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<td>0.40%</td>
</tr>
<tr>
<td>Asian</td>
<td>56</td>
<td>11.13%</td>
</tr>
<tr>
<td>Black or African American</td>
<td>16</td>
<td>3.18%</td>
</tr>
<tr>
<td>Hispanic or Latino</td>
<td>20</td>
<td>3.98%</td>
</tr>
<tr>
<td>Native Hawaiian or Other Pacific Islander</td>
<td>3</td>
<td>0.60%</td>
</tr>
<tr>
<td>White</td>
<td>373</td>
<td>74.16%</td>
</tr>
<tr>
<td>Other</td>
<td>17</td>
<td>3.38%</td>
</tr>
<tr>
<td>Prefer not to answer/No answer</td>
<td>16</td>
<td>3.18%</td>
</tr>
<tr>
<td><strong>Class Standing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>184</td>
<td>36.58%</td>
</tr>
<tr>
<td>Sophomore</td>
<td>209</td>
<td>41.55%</td>
</tr>
<tr>
<td>Junior</td>
<td>72</td>
<td>14.31%</td>
</tr>
<tr>
<td>Senior</td>
<td>31</td>
<td>6.16%</td>
</tr>
<tr>
<td>Other</td>
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<td>1.39%</td>
</tr>
<tr>
<td><strong>Major</strong></td>
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<td></td>
</tr>
<tr>
<td>Engineering</td>
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<td>82.11%</td>
</tr>
<tr>
<td>Other STEM</td>
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<td>12.52%</td>
</tr>
<tr>
<td>Other</td>
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<td>2.78%</td>
</tr>
<tr>
<td>None</td>
<td>13</td>
<td>2.58%</td>
</tr>
<tr>
<td><strong>Minor</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering</td>
<td>14</td>
<td>2.78%</td>
</tr>
<tr>
<td>Other STEM</td>
<td>92</td>
<td>18.29%</td>
</tr>
<tr>
<td>Other</td>
<td>55</td>
<td>10.93%</td>
</tr>
</tbody>
</table>
**Instrumentation.** This study relied on two instruments related to self-efficacy. The first is an eight-question domain-specific Three-Dimensional Modeling Self-Efficacy scale (adapted from Denson & Hill, 2010). This scale must be validated which is a fundamental component of this research. Figure 5.2 provides the eight items in the assessment, which are answered using a seven-point Likert scale with one indicating “lowest agreement” and seven indicating “highest agreement.”

1. I feel that I am good at visualizing/manipulating 3D objects in space.
2. I have confidence in my ability to model 3D objects using computers.
3. I am confident enough in my 3D modeling to help others model 3D objects.
4. I am good at finding creative ways to model 3D objects.
5. I believe I have the talent to do well in 3D modeling.
6. I feel comfortable using 3D modeling software.
7. I feel confident in my ability to create 3D objects in a variety of ways.
8. I feel I can communicate 3D objects to other peers.

*Figure 5.2. The Three-Dimensional Modeling Self-Efficacy scale.*

The second instrument is the 22 item the Self-Efficacy for Learning (SEL) developed by Klobas, Renzi, and Nigrelli (2007). These questions (Figure 5.3) are answered using a ten-point Likert scale with one indicating “I am definitely not able to do this” and ten indicating “I can definitely do this.”

1. I am able to organize my activities so that I can meet all course deadlines.
2. Soon after the end of a lesson, I am able to remember all of the key concepts.
3. I can understand all of the key concepts covered in my coursework.
4. I am able to explain to my fellow students, in a way they can understand, all of the key concepts covered in courses.
5. After sitting for an examination, I am able to remember all of the key concepts covered in courses.
6. When I find something new about a topic that I am studying, I am always able to connect it with other things that I know about the topic.
7. I always know how to get up to date on a topic if my knowledge of it is outdated.
8. Even when I haven’t participated in a lesson, I can always understand the concepts covered in the lesson by reading a textbook.
9. I am never embarrassed to ask a teacher for clarification.
10. I am always able to identify the most appropriate person to help me resolve a problem related to my study.
11. I am always able to identify the quality of fellow group members’ contributions when I participate in group activities.
12. I am always able to relate the notes I have made during a lesson with the topics covered in the course text or readings.
13. It is always easy for me to understand new information, even on a topic that does not interest me very much.
14. It is always easy for me to connect new information about a topic that interests me with other pieces of information.
15. During a course, if we are given a new task to complete, I can always complete it by applying the knowledge that I obtained from lessons.
16. Soon after the end of a lesson, I am always able to distinguish the most important concepts from concepts of less importance.
17. If, as part of a course, I participate in a forum or online discussion, I am always able to identify those messages which will improve my understanding of the material covered in the course.
18. I always find it easy to join a group of fellow students to study or complete course activities.
19. I am always able to use the library and library services to select appropriate books and articles for an assignment.
20. After a lesson, I am always able to integrate concepts described by the teacher with those presented in course texts and readings.
21. When I write an essay for a course, I am always able to incorporate knowledge gained from other sources.
22. I am always able to help other students solve problems based on concepts described in a lesson.

Figure 5.3. The Self-Efficacy for Learning scale (SEL) originally developed by Klobas, Renzi, & Nigrelli (2007).

Reliability. Reliability (internal consistency) is the degree to which scale items within an instrument are intercorrelated, providing evidence of a commonly related construct (Trochim, Donnelly, & Arora, 2015). The most common method for determining the internal consistency of an instrument is to determine the coefficient alpha, commonly referred to as Cronbach’s alpha (Drost, 2011). Cronbach’s alpha can be used to examine the unidimensionality of an instrument and, when coupled with factor analysis, can provide further evidence of a scale’s unidimensionality (Tavakol & Dennick, 2011). Values ranging
from 0.70 to 0.95 are considered to be sufficient to consider an instrument reliable (Drost, 2011). For this study, an alpha of 0.70 was used as a minimum value to determine reliability.

**Validity.** To address the second research question, whether or not the self-efficacy scales used in this study are valid, the researcher first examined the items in the instrument to determine if the instrument has face validity. Face validity is the degree to which an instrument appears to measure the constructs the instrument purports to assess from the perspective of a participant (Weiner & Craighead, 2010). Although subjective and often viewed as a weak form of construct validity (Drost, 2011), face validity was included to support the assertion that the instrument is appropriate for measuring the construct of 3D modeling self-efficacy (Weiner & Craighead, 2010). Face validity relies on the likely opinion of the test taker rather than expert(s) opinion and differs from content validity in that is not a true assessment of the construct(s) measured (Furr & Bacharach, 2013). Face validity is ultimately a subjective judgement of the researcher(s) regarding instruments used (Drost, 2011) and is used, in part, to differentiate between the domain-specific and non-domain-specific instruments used in this research.

Second, the participant’s score on the Three-Dimensional Modeling Self-Efficacy scale results was compared to their final exam, project, and course grades to examine any relationships as evidence of concurrent validity. Evidence of concurrent validity exists if the final exam, project, and course grades correlate with the Three-Dimensional Modeling Self-Efficacy scale (Furr & Bacharach, 2013).
Lastly, the researcher examined whether evidence of discriminant validity exists by comparing the relationship between the students’ scores on the Three-Dimensional Modeling Self-Efficacy scale to the students’ scores on the self-efficacy of learning instrument (Furr & Bacharach, 2013). Since, theoretically, self-efficacy instruments need to be domain specific (Bandura, 2006), comparison of these two instruments should show low or non-existent correlations between them.

**Exploratory factor analysis.** To examine the underlying factor structure of the Three-Dimensional Modeling Self-Efficacy scale, this researcher conducted an exploratory factor analysis (EFA). EFA is also used to eliminate items poorly correlated with the desired factor, reduce the number of items in the instrument, and create a parsimonious assessment that captures the desired construct (Burton & Mazerolle, 2011; Furr & Bacharach, 2013). For this study, the goal is to understand the attributes related to self-efficacy as they relate to academic outcomes in an introductory engineering graphics course. As such, EFA was chosen over principle component analysis (PCA) because PCA is desired more for its role in item reduction and factor extraction rather than an investigation of the underlying factor structure (Burton & Mazerolle, 2011).

Prior to conducting the EFA, the adequacy of the sample was evaluated. The literature recommends a minimum of 300 participants and the ratio of respondents to variables should be 10:1 (Yong & Pearce, 2013). This study has a sample size of 503 participants, well above the recommended minimum size for EFA. The sampling adequacy was also assessed to determine if the inter-item correlations are suitable for EFA (Burton &
An examination of the instruments correlation matrix was performed to ensure that the correlation matrix is not an identity matrix and that all items correlate with at least one other item with an $r$ if at least .30 (Burton & Mazerolle, 2011; Yong & Pearce, 2013).

Additionally, sampling adequacy was assessed using the Kaiser-Meyer-Olkin (KMO) correlation. KMO correlation values above .60 are regarded as sufficient to continue with an EFA (Burton & Mazerolle, 2011). Similarly, the examination of the correlation matrix for inter-item correlation can be performed using Bartlett’s test of sphericity. Bartlett’s test of sphericity produces a chi-square output that, if significant, indicates the correlation matrix is not an identity matrix (Burton & Mazerolle, 2011). If Bartlett’s test of sphericity and the KMO correlation results indicate sampling adequacy and the lack of an identity matrix, the EFA can be performed on the data. Because of the objectivity of Bartlett’s test of sphericity and KMO correlations rather than “eyeballing” the correlation matrix, Stata 14 was used to conduct these two tests to determine the appropriateness of the data for EFA.

**Determination of factors.** Several considerations are present in the decision as to which factors to retain to investigate the latent constructs in the instrument. Common methods for identification of factors to retain include Kaiser’s criterion, scree test, *a priori* knowledge, total variance extracted, and parallel analysis (Burton & Mazerolle, 2011; Furr & Bacharach, 2013; Yong & Pearce, 2013). There is no “better” method of factor retention determination and it has been described as being more art than science with the triangulation of several methods of analysis being common practice (Yong & Pearce, 2013).
The researcher’s *a priori* knowledge of the instruments, constructs of interest, and the context in which the study was conducted are important factors in the analysis of the factor loadings and determining which factors to retain. *Kaiser’s criterion*, which recommends factors with eigenvalues greater than 1.00 are retained, is the most common method in determining factor retention (Burton & Mazerolle, 2011; Yong & Pearce, 2013). The scree test (analysis of the scree plot), so named as an analogy to rocks and boulders stacking up at the bottom of a cliff, is a graphical method of factor retention analysis and is comprised of the eigenvalues plotted on an x-y axis (Yong & Pearce, 2013). The point in the scree plot where the vertical component of the curve straightens out and becomes horizontal is referred to as the “elbow” and all factors at or before that point should be retained (Yong & Pearce, 2013). These two methods of analysis were the primary method of analysis used in determining the number of factors retained in this study.

**Regression analysis.** Correlation analysis was used to determine the existence of the relationship between Three-Dimensional Modeling Self-Efficacy and self-efficacy of learning and student academic outcomes under the assumption that both self-efficacy measures would correlate significantly with the outcome measures but not with each other (Bandura, 2006). To account for potential differences in grades that may be related to the individual course section in which they were enrolled, a group-mean transformation was applied to the scores for final course, exam, and project grades whereby the scores were mean centered within the individual course section rather than the average across all sections (Paccagnella, 2006).
To determine the effect a student’s level of three-dimensional modeling self-efficacy, a regression analysis was employed. Regression analysis is used to examine the relationship between an independent or predictor variable and a dependent or criterion variable (Trochim, Donnelly, & Arora, 2015). For this study, the participants’ mean scores on the Three-Dimensional Modeling Self-Efficacy scale are the predictor (independent) variables used in the analysis with the final course, project, and exam grades as the criterion (dependent) variables.

Findings

Item level descriptive statistics for the Three-Dimensional Modeling Self-Efficacy scale are displayed in Table 5.2. Stata 14 was used to analyze the data in this study.

Table 5.2

<table>
<thead>
<tr>
<th>Item</th>
<th>n</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
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<td>1</td>
<td>503</td>
<td>5.53</td>
<td>1.04</td>
</tr>
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<td>2</td>
<td>503</td>
<td>5.73</td>
<td>.90</td>
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<tr>
<td>3</td>
<td>503</td>
<td>5.47</td>
<td>1.14</td>
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<tr>
<td>4</td>
<td>503</td>
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<td>1.16</td>
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<td>5</td>
<td>503</td>
<td>5.59</td>
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</tr>
<tr>
<td>6</td>
<td>503</td>
<td>5.66</td>
<td>1.07</td>
</tr>
<tr>
<td>7</td>
<td>503</td>
<td>5.50</td>
<td>1.11</td>
</tr>
<tr>
<td>8</td>
<td>503</td>
<td>5.45</td>
<td>1.16</td>
</tr>
<tr>
<td>Mean Score</td>
<td>503</td>
<td>5.54</td>
<td>.90</td>
</tr>
</tbody>
</table>

Reliability. The reliability of the Three-Dimensional Modeling Self-Efficacy scale was determined using Cronbach’s alpha statistic to address the first research question, “Is the
domain-specific Three-Dimensional Modeling Self-Efficacy scale reliable?” Based on the stated threshold of .70 (Drost, 2011), the eight-item Three-Dimensional Modeling Self-Efficacy scale is reliable ($\alpha = .94$) with an average inter-item covariance of .83.

**Exploratory factor analysis. Factorability.** Toward investigating the underlying factor structure of the Three-Dimensional Modeling Self-Efficacy scale and addressing our third research question, the researcher conducted an exploratory factor analysis. The initial step in EFA is to determine the adequacy of the sample. To accomplish this, the researcher used three methods of analysis: examination of the correlation matrix, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, and Bartlett’s test of sphericity. Table 5.3 displays the correlation matrix. Analysis of the correlations revealed that all nine items significantly correlated with at least one other item with a minimum coefficient of .30 (Burton & Mazerolle, 2011).

Table 5.3

Intercorrelations for Items in the 3D Modeling Self-Efficacy Scale

<table>
<thead>
<tr>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
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<tbody>
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<td>1</td>
<td>-</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>.62</td>
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<td>.65</td>
<td>.61</td>
<td>.70</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note.* Coefficients in bold are significant at $p < .05$ level.
An examination of the Kaiser-Meyer-Olkin measure of sampling adequacy suggested the sample was adequate for factoring (KMO = .80) and Bartlett’s test of sphericity was significant ($\chi^2 (36) = 233.452, p < .001$) indicating the sample was not an identity matrix. These two measures, combined with the analysis of the correlation matrix, support the researcher’s contention that the sample is factorable (Burton & Mazerolle, 2011).

**Factor determination.** Once the factorability of the sample was determined, an EFA was conducted to determine the number of factors underlying the Three-Dimensional Modeling Self-Efficacy scale. The results of the EFA for the eight-item scale can be found in Table 5.4.

Table 5.4

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor loading</th>
<th>Communality</th>
</tr>
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<tbody>
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<td>2</td>
</tr>
<tr>
<td>1</td>
<td>.72</td>
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<tr>
<td>2</td>
<td>.83</td>
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<td>4</td>
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<td>.85</td>
<td>-.03</td>
</tr>
<tr>
<td>8</td>
<td>.73</td>
<td>.13</td>
</tr>
</tbody>
</table>

Eigenvalue | 5.05 | .11 | .03 |
% of Variance* | 63.14 | 1.44 | .34 |

*Trace of correlation matrix as divisor.
Using Kaiser’s criterion, factors with eigenvalues greater the 1.00 were retained (Yong & Pearce, 2013). To confirm this method, the researcher also examined the total variance explained. Factor one explained 63.14% of the variance in the sample; greater than our determination criteria of .50 (Beavers et al., 2013); the trace of the correlation matrix was used in the analysis because the total variance explained was greater than one. Both methods suggest a single factor structure for the Three-Dimensional Modeling Self-Efficacy scale. The single factor solution is displayed in Table 5.5.

Table 5.4

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor loading</th>
<th>Communality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.72</td>
<td>.52</td>
</tr>
<tr>
<td>2</td>
<td>.83</td>
<td>.68</td>
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<td>3</td>
<td>.84</td>
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<td>.73</td>
<td>.54</td>
</tr>
<tr>
<td>Eigenvalue</td>
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<td></td>
</tr>
<tr>
<td>% of Variance*</td>
<td>63.14</td>
<td></td>
</tr>
</tbody>
</table>

*Trace of correlation matrix as divisor.

**Validity.** As noted previously, the researcher first determined whether the Three-Dimensional Modeling Self-Efficacy scale had face validity. Although subjective and often
viewed as a weak form of construct validity (Drost, 2011), face validity was included to support the assertion that the instrument is appropriate for measuring the construct of Three-Dimensional Modeling Self-Efficacy (Weiner & Craighead, 2010).

Toward addressing the second research question – Is there evidence of validity in the domain-specific Three-Dimensional Modeling Self-Efficacy scale? – a multiple linear regression analysis was performed. Prior to the regression analysis, the dependent variables of student final exam, project, and course grades were group mean-centered. The predictor variables (Three-Dimensional Modeling Self-Efficacy and self-efficacy of learning) were regressed on to the dependent variables using Stata 14. A partial correlational analysis was also performed using both predictor and dependent variables (Table 5.6.).

Table 5.5

Intercorrelations for Predictor Variables and Student Grades

<table>
<thead>
<tr>
<th></th>
<th>Three-dimensional modeling self-efficacy</th>
<th>Self-efficacy of learning</th>
<th>Final course grade</th>
<th>Final project grade</th>
<th>Final exam grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-dimensional modeling self-efficacy</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-efficacy of learning</td>
<td>.49**</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final course grade</td>
<td>.27**</td>
<td>.13**</td>
<td>–</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final project grade</td>
<td>.18**</td>
<td>0.09*</td>
<td>.70**</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Final exam grade</td>
<td>.19**</td>
<td>.06</td>
<td>.61**</td>
<td>.26**</td>
<td>–</td>
</tr>
</tbody>
</table>

*Note.**Significant at $p < .001$ level. *Significant at $p < .05$ level. Variables for student grades were group-mean centered.
Partial correlation analysis revealed significant positive associations between the variables of the Three-Dimensional Modeling Self-Efficacy scale and students’ final course, project and exam grades. The Self-Efficacy of Learning scale has a statistically significant correlation with students’ final course and final project grades; however, no statistically significant correlations were found between the Self-Efficacy of Learning scale and students’ final exam grade. Both self-efficacy scales used in this study indicated a statistically positive correlation with each other, \( r = .49, p < .001 \). The significant correlation found between the two self-efficacy instruments is remarkable in that it is contrary to Bandura’s (2006) assertion that both self-efficacy measures would correlate significantly with the outcome measures but not with each other.

To address the fourth research question – What effect does a student’s Three-Dimensional Modeling Self-Efficacy have on their academic outcomes in an undergraduate introductory engineering graphics course? – and investigate evidence of discriminant validity, the predictor variables were analyzed and their combined effect on student final exam, project, and course grades were calculated and are displayed in Table 5.7. For student final course grades, the predictor variables explained 6.82\% of the total variance, \( R^2_{\text{adj}} = .0682, F(2, 500) = 19.37, p < .001 \). For student final project grades, the predictor variables explained 2.92\% of the total variance, \( R^2_{\text{adj}} = .0292, F(2, 500) = 8.56, p < .001 \). For student final exam grades, the predictor variables explained 3.43\% of the total variance, \( R^2_{\text{adj}} = .0343, F(1, 501) = 18.84, p < .001 \). It should be noted that simple linear regression – with only the
Three-Dimensional Modeling Self-Efficacy score as a predictor variable – was used for the students’ exam grade due to the lack of a statistically significant correlation (with $\alpha = .05$) between student exam scores and their score on the Self-Efficacy of Learning scale, $r = .06, p = .160$.

Table 5.6

Results of the Regression Analysis for the Three-Dimensional Modeling Self-Efficacy and Self-Efficacy of Learning Scales

<table>
<thead>
<tr>
<th>Academic outcomes</th>
<th>$t$</th>
<th>$p$</th>
<th>$\beta$</th>
<th>$F$</th>
<th>df</th>
<th>$p$</th>
<th>$R^2_{adj}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final course grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall Model</td>
<td>19.37</td>
<td>500</td>
<td>&lt; .001</td>
<td>.068</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three-dimensional</td>
<td>5.43</td>
<td>&lt; .001</td>
<td>1.85</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>modeling self-efficacy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-efficacy of learning</td>
<td>-.010</td>
<td>.994</td>
<td>-.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final project grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall Model</td>
<td>8.56</td>
<td>500</td>
<td>&lt; .001</td>
<td>.029</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three-dimensional</td>
<td>3.59</td>
<td>&lt; .001</td>
<td>1.84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>modeling self-efficacy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self-efficacy of learning</td>
<td>.02</td>
<td>.980</td>
<td>.009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final exam grade</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall Model</td>
<td>18.84</td>
<td>501</td>
<td>&lt; .001</td>
<td>.034</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Three-dimensional</td>
<td>4.34</td>
<td>&lt; .001</td>
<td>1.77</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>modeling self-efficacy</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

There is significant dependence of Three-Dimensional Modeling Self-Efficacy on the students’ final course grades ($b = 1.85, t(500) = 5.34, p < .001$), final project grades ($b = 1.84, t(500) = 3.59, p < .001$), and final exam grades ($b = 1.77, t(501) = 4.34, p < .001$). For
instance, for every point increase in the Three-Dimensional Modeling Self-Efficacy in a student participating in the introductory engineering graphics course used in this study, their final course grade can be expected to be 1.85 points greater, their final project to be 1.84 points greater, and their final exam grade to be 1.77 points greater than the class average.

The Self-Efficacy of Learning scale did not display any statistically significant impact when included in the multiple regression model with Three-Dimensional Modeling Self-Efficacy for the students’ final course grade, $b = -0.002$, $t(500) = -0.01$, $p = 0.994$ or final project grade, $b = 0.01$, $t(500) = 0.02$, $p = 0.980$. The final exam grade was not included in the regression model that included the Self-Efficacy of Learning scale due to its lack of statistically significant correlation between the two variables.

**Discussion**

There exists a quantifiable need to examine different approaches to improving the rates of student retention and persistence within the engineering education pipeline. Non-cognitive factors, such as self-efficacy, are positively associated with factors such as persistence and retention in education (Nagaoka et al., 2013). In this study, self-efficacy was examined in the context of three-dimensional modeling as this skill is a core component in engineering graphics education which is, in turn, a key element of engineering education. The dearth of specific research into this specific domain also meant that there was no domain specific self-efficacy instruments as required to assess accurately the construct (Bandura, 1997). As such, the researcher sought to examine the psychometric properties of a Three-Dimensional Modeling Self-Efficacy scale among students in an undergraduate introductory
engineering graphics course. As a secondary objective, this investigation also looked at what, if any, impact a student’s Three-Dimensional Modeling Self-Efficacy had on major academic outcomes in the course. Toward these goals, 503 students took both the Three-Dimensional Modeling Self-Efficacy and self-efficacy of learning assessments. Their scores on these assessments were then compared to their final course, project, and exam grades. The self-efficacy of learning scale was not the primary measure in this study but used to determine whether evidence of discriminant validity exists.

The Three-Dimensional Modeling Self-Efficacy scale demonstrates strong evidence of reliability among the population used in this study. An alpha of 0.70 was used as a minimum value to determine reliability in this study and a Cronbach’s alpha coefficient of .94 was calculated.

Further investigation into the psychometric properties of the Three-Dimensional Modeling Self-Efficacy scale was needed beyond reliability. To examine the instrument further, an exploratory factor analysis was employed to assess the underlying factor structure. As noted previously, analysis of the Three-Dimensional Modeling Self-Efficacy scale reveals that the instrument measures a single construct.

Since self-efficacy and its measurement are domain specific (Bandura, 1997) the Three-Dimensional Modeling Self-Efficacy scale was compared to a self-efficacy scale designed to assess general academic self-efficacy. Although these two scales showed moderate and statistically significant association $r = .49$, regression analysis clearly shows Three-Dimensional Modeling Self-Efficacy has a significant contributing role in a student’s
grades, a student’s self-efficacy of learning had little or no impact on academic outcomes. That is not to say that general self-efficacy of learning does not play a role in either academic outcomes or persistence; in this study, the impact is negligible. It does, however, provide evidence of discriminant validity.

A student’s Three-Dimensional Modeling Self-Efficacy explains approximately 7% of the variance in their final course grade in this study. Although a small contribution to academic performance, it is in keeping with other self-efficacy studies (Pajares, 1997). Student sources of self-efficacy and methods by which to create interventions aimed at improving performance, retention, or persistence are beyond the scope of this study. What is of relevance is that the results of the Three-Dimensional Modeling Self-Efficacy scale are consistent with other self-efficacy measures used in other studies and this consistency serves to provide evidence of the instruments validity within the context of this study.

When the evidence of reliability, face validity, single underlying factor structure, discriminant validity, and consistency with other self-efficacy studies are viewed collectively, the Three-Dimensional Modeling Self-Efficacy instrument demonstrates sound psychometric properties and evidence of construct validity. It should be noted that this study alone, along with a lack of analysis into factors related to the instrument’s convergent validity with the construct of self-efficacy, construct validity is not a claim made by the author of this paper.
Limitations and Future Study

Several other limitations prevent a decisive conclusion being drawn concerning the psychometric soundness of the Three-Dimensional Modeling Self-Efficacy scale. This research was conducted in a highly ranked land-grant university with a heavy engineering focus. Admission requirements limit the available population to those students who generally performed above average in both high school coursework and SAT scores. Further study using a more academically diverse population is needed to gain a greater understanding of the psychometric properties of the instrument used.

The population in this study is also not diverse with respect to race/ethnicity or gender. Both of these groups are underrepresented in engineering, and deeper study of the non-cognitive factors related to their participation in engineering is needed. This instrument may provide insight into the lack of minority participation in engineering; however, further validation is needed to properly assess the Three-Dimensional Modeling Self-Efficacy instrument and its use with these populations.

Finally, self-efficacy is only one non-cognitive factor, and three-dimensional modeling is only one part of engineering graphics and represents an even smaller share of engineering education. Further instrument development toward gaining a more complete picture of the non-cognitive factors related to academic success and persistence in engineering graphics and engineering education as a whole. Although this study provides some insight, it offers no solution to a problem that has been identified as one of national import.
Conclusion

This study examined a Three-Dimensional Modeling Self-Efficacy instrument within an introductory engineering graphics education context. There is strong evidence of sound psychometric properties with evidence pointing toward a valid and reliable instrument with the data used in this study. Both deeper and broader investigation into the psychometrics is needed as well as further development of a comprehensive instrument to measure the noncognitive factors of students in engineering graphics education. This instrument provides another tool by which to understand better student performance and potentially develop and assess interventions directed at increasing the academic outcomes and persistence of students in a field that shows both increasing demand and importance as we continue into the 21st-century.
References


Chapter 6

The Gender Gap in Engineering Graphics:
A Comparison of Male and Female Self-Efficacy Levels and Academic Outcomes

Introduction

The government of the United States has identified engineering is an area of national need and the nation’s status as a leader on the world stage faces potential diminishment if current trends in degree attainment continue (Kanny, Sax, & Riggers-Piehl, 2014). An ongoing topic of concern is the continuing underrepresentation of women in the engineering workforce and in the academic pipeline that feeds it. Despite the many initiatives and foci of emphasis aimed at addressing the lack of parity between women and men in engineering professions (e.g. equitable K-12 classroom experiences, recruitment, and female engineering self-efficacy), female enrollment in engineering degree programs continues to lag significantly behind their male counterparts (Kanny et al., 2014).

The engineering workforce has seen some growth in the percentage of females in its ranks over the last half century. In 1960, women made up about 1% of engineers in the United States and broke into double-digit participation sometime near the end of the 20th century (Corbett & Hill, 2015). At issue is an apparent stagnation (or at least – minimal levels of growth) in the number of women in engineering since the start of the new millennium. Figure 6.1 illustrates this sluggish trend adjustment with only 1% growth in female engineers over a recent 13-year period. The underrepresentation of women in engineering is of grave concern to many as it is acknowledged in the extant literature that
diverse classroom and work environments not only foster creativity and greater problem-solving skills, but that the lack diversity in science, technology, engineering, and mathematics (STEM) may actually compromise the quality of scientific and engineering output (Kanny et al., 2014).

Figure 6.1. Percentage of women in engineering field 1960-2013 based on U.S. census data (Corbett & Hill, 2015).

Kanny et al. (2014) posited two questions regarding research into the gender gap in their meta-analysis: “Why do women enroll in STEM majors at lower rates than men?” and “Have we been studying the right things?” (p. 128). They go further to suggest that possible reasons for the persistent gender gap are the inaccurate identification of the key factors necessary to facilitate equitable workforce gender representation and a lack of new or evolving explanations for the deficiency in female STEM participation.

When investigating the gender gap in STEM fields, the bulk of scholarly work has examined STEM as a single construct rather than as its constituent subfields (Kanny et al.,
2014). Women are better represented in fields such as biology, but the trends for women in computer science have actually decreased (Corbett & Hill, 2015). This exemplifies the need to disaggregate the STEM subfields in gender gap research and examine potential differences in how and why women select and choose to remain in a particular subfield. Kanny et al. (2014) describe the lack of subfield research as doing a “disservice to the topic of the gender gap by presuming that the explanations for women’s under-enrollment in computer science (for example) are the same as those for engineering or physics” (p. 143).

The current research investigates one area, three-dimensional modeling, within engineering graphics education, which is a fundamental and common subfield of engineering. The extant literature related to engineering graphics is a domain in which discussion of the construct of interest in this study, self-efficacy, is still nascent.

**Addressing the Engineering Gender Gap**

The increases shown above (Figure 6.1) correlate with intervention initiatives, programs, and policies designed to specifically to increase workforce participation in the areas of science and engineering. One such initiative, the National Science Foundation (NSF), was chartered in 1950 in part “to promote the progress of science; to advance the national health, prosperity, and welfare…” (Priest, 1950). NSF is the only federal agency with programs specifically devoted to engineering education and has as a core tenant of its mission to “cultivate a world-class, broadly inclusive science and engineering workforce” (Lichtenstein, Chen, Smith, & Maldonado, 2014; Priest, 1950)
The formation of NSF started a movement that continued in the 1970s and early 1980s with a push to expand the STEM workforce by targeting women and minorities. During this period, domestic issues replaced foreign threats (e.g. the space-race and Soviet nuclear capabilities) as primary concerns of many Americans (Lichtenstein et al., 2014). Civil rights and women’s movements began to impact federal policy making with calls for greater efforts by federal organizations such as NSF to assist with increasing the participation rates in science and engineering by women and minorities (Lichtenstein et al., 2014). Advocacy for the broadening of participation specifically highlighting the dearth of female and minorities in the STEM workforce led to the passage of the Science and Technology Equal Opportunity Act of 1980 prioritizing federal funding toward increasing the numbers of developing skills in STEM areas among women and minorities (Lichtenstein et al., 2014; Lucena, 2005).

Whereas the 1970s saw a shift from foreign threats to domestic concerns, the 1980s ushered in a shift from military competition to economic pressures from countries such as Japan as a threat to American technologic and economic preeminence. This pressure, combined with an American recession, lead to efforts to identify and train a workforce that could compete in the global marketplace that included the participation of women and minorities flowing into the now ubiquitous STEM pipeline metaphor (Lichtenstein et al., 2014). The period starting in the 1970s and continuing into the early 1980s identified a very prominent gender gap in STEM fields and active advocacy and was the period in which female participation in engineering showed the largest gains (see Figure 6.1).
In addition to issues surrounding women entering the STEM pipeline, the late 1980s and 1990s saw the emergence of research identifying educational retention and career persistence as impediments to broadening female STEM workforce participation. The 1990s saw an attrition rate increase among students in STEM disciplines especially among females and minorities (Lichtenstein et al., 2014). A congressional report in 1989 found only 50% of students entering science and engineering programs completed them, a trend that has only marginally improved (59% now graduate) but female and minority students have not yet even reached the 1989 benchmark with only 45% completing degree programs currently (Kelly, Ernst, & Clark, 2017; Lichtenstein et al., 2014). Other studies and reports in the late 1980s suggested that female students also have disproportionately lower interest in STEM subjects and in a 1986 study, less than 3% of female undergraduates reported an intention to major in engineering as opposed to nearly 18% of male students (Lichtenstein et al., 2014).

The arrival of the 21st century did not bring with it a boon to women entering university engineering programs. The recruitment and retention of female students in these programs have remained stagnant as have the number of women in the engineering profession has only increased by 1% since the year 2000 and, as of 2011, represent less than 18% of engineering students (Lichtenstein et al., 2014). This dearth of female engineering students persists even in the face of female students representing 57% of the college student population (Chen, 2013).

Research into the phenomenon of low female participation rates reveals that male and female high school students are equally likely to express interest in pursuing STEM degrees
as the White males who dominate enrollment and are equally qualified to do so. They indicate that the K-12 gender achievement gap has closed with female students performing on par with males (Burgoyne et al., 2010), especially in subjects such as math and science, which are indicators of engineering education pursuits.

Even with parity concerning ability and interest upon exiting high school, qualified and capable women are choosing to both not pursue engineering as a profession and to leave university engineering programs once they begin their education. There remains a gap in both our understanding and effectiveness when it comes to closing the gender gap in engineering. The last decade and a half has shown little or no growth in the number of women in engineering and the trend lines appear to have plateaued. Increasing the proportions of women not only recruited into and retained in engineering degree programs but the workforce as well is a necessary and laudable goal within engineering education. The small percentage of women in the engineering workforce can be explained in part by the low college enrollment levels (Chen, 2013; National Science Board, 2015) and that only 35% of engineering degree recipients stay in the field (Olson & Riordan, 2012). The reasons underlying the low participation of women has been heavily investigated; however, the problem persists with targeted interventions taking substantial time to be developed, researched, and refined.

This paper offers research into one domain fundamental and shared within engineering education – engineering graphics and three-dimensional modeling – that has not been part of the extant literature and is a domain in which discussion of the construct of
interest in this study, self-efficacy, is still nascent. This study presents research into female self-efficacy in an undergraduate engineering graphics course and investigates the synergistic.

**Self-Efficacy in Engineering Education**

Self-efficacy has been shown to be positively associated with performance among introductory engineering graphics students (Metraglia, Villa, Baronio, & Adamini, 2016). Self-efficacy has been identified as having a significant impact on the educational outcomes and persistence in academic settings (Bandura, 1997; Lent, Brown, & Larkin, 1984; Pajares, 1997). Self-efficacy has also been shown to be a predictor of achievement and persistence among engineering students (Loo & Choy, 2013; Ponton, Edmister, Ukeiley, & Seiner, 2001). In addition to the positive relationship between self-efficacy beliefs and academic success and persistence generally, self-efficacy in engineering domains has been found to increase significantly the self-efficacy beliefs of college engineering students and, by extension, their choices to pursue and persist in engineering (Fantz, Siller, & Demiranda, 2011).

There is a growing body of evidence that self-efficacy plays a significant role in predicting student outcomes and persistence in engineering education classes. In a pair of studies, (Lent et al., 1984; Lent, Brown, & Larkin, 1986) associations between self-efficacy and academic outcomes were evident. In the latter study, the use of hierarchical regression analysis suggested that self-efficacy beliefs contributed a significant amount of unique variance toward the prediction of student academic outcomes (Lent et al., 1986). Vogt,
Hocevar, & Hagedorn (2007) also confirmed previous research findings that self-efficacy levels are strongly associated with academic outcomes.

Lent’s work continued with a study of 487 students in introductory engineering courses (2005). The study findings were consistent with other research in that variable related to social cognitive theory such as self-efficacy are a high predictive factor for academic interests and goals in engineering. The study also used an academic self-efficacy instrument rather than a domain-specific scale. The use of a general scale with predictive outcomes for engineering students strengthens the rationale for this study comparing specific and general instruments.

Hutchison, Follman, Sumpter, & Bodner (2006) identified nine influential factors related to first-year engineering students’ self-efficacy beliefs. They also examined the students’ self-efficacy beliefs by gender. Understanding/learning was the greatest indicated factor contributing to self-efficacy in the study. This was followed by drive and motivation, teaming, computing ability, help, working assignments, problem-solving ability, enjoyment interest and satisfaction, and grades respectively. Only two factors held statistically significant differences between male and female students. Understanding/learning course material was indicated as influencing self-efficacy beliefs by 55% of male and 77% of female students \( (p < .001) \) and getting help was indicated by 38% of female students opposed to 19% of males \( (p < .001) \).

Hutchison et al. (2006) determined that eight of the nine above indicated factors of self-efficacy beliefs comport with the four sources of self-efficacy identified by Bandura
(1997). Drive and motivation, or desire to succeed in the engineering course examined in the study, was not included as a contributor to self-efficacy in agreement with Bandura’s (1997) opinion that motivation biases the individual’s processing of efficacy information (Hutchison et al., 2006).

As with most studies, a 2011 study of an introductory design course confirmed self-efficacy as being associated with student achievement (Purzer, 2011). Purzer found that initial self-efficacy scores did not act as a predictive factor for academic outcomes at the end of the semester; however, end-of-semester scores were associated with gains in self-efficacy. Purzer uses these findings to suggest self-efficacy scores before an intervention do not share the predictive validity of the post-intervention assessment. This appears to run contrary to the extant literature and is limited by a small sample size (n = 22) and the single environment in which the study was conducted. Although potentially an outlier, this study does question if self-efficacy increases with learning and content knowledge and that content knowledge is the true cause for variance in academic outcomes rather than self-efficacy. The suggestion that self-efficacy is dependent on knowledge or cognitive ability has frequently been refuted and self-efficacy shown to be an independent contributing factor to performance (Maier & Curtin, 2005).

**Persistence**

Self-efficacy has been associated positively with persistence as well as academic performance (Fantz et al., 2011; Pajares, 1997). Colleges and universities are seeing increasing undergraduate enrollment in science and engineering disciplines, but less than half
of the graduates are entering the workforce in engineering (35%) and science (14%) fields (National Science Board, 2016). Self-efficacy has been shown to be significantly and positively associated with students’ intention to persist in engineering majors (Lent et al., 2015); however, entering the professional workforce after graduation may relate more to perceived value rather than self-efficacy (Mamaril, Usher, Li, Economy, & Kennedy, 2016). Although career persistence is of interest in engineering education, it is separate from the goals of this research. As there is an abundance of evidence that self-efficacy is positively associated with educational attainment and persistence (Bandura, 1997), determining if this association is present in engineering graphics is valuable to the field of engineering graphics education.

Lower levels of self-efficacy decrease the desire to persist in engineering especially in women (Godwin, Potvin, Hazari, & Lock, 2016). There is also significant evidence that self-efficacy levels significantly impact the academic attainment levels for both male and female undergraduate students (Raelin et al., 2014). A better understanding of the factors related to both low and high self-efficacy levels may aid in identifying pedagogical and instructional methods to increase the levels of persistence in engineering and engineering graphics education.

**Gender Differences**

Male students continue to dominate the classrooms and represent greater than 80% of graduates of undergraduate engineering degree programs (Godwin et al., 2016). Despite
lower numbers, female students perform the same academically yet have lower levels of self-efficacy (Godwin et al., 2016).

There are conflicting findings when gender differences in engineering self-efficacy are examined. Hutchison et al. (2006) reported differences in some factors influencing males and females differently. The levels of self-efficacy were not reported as significantly different. Similarly, no gender differences were reported by Towle et al. (2005) among 219 engineering and science students in a study comparing self-efficacy beliefs to mental spatial rotation ability. Vogt et al. (2007) found significant differences in self-efficacy beliefs between male and female engineering students. This finding comports with the literature and previous findings in similar studies. They also found that their differences in the levels of influence self-efficacy have on other constructs associated with academic outcomes such as help-seeking, critical thinking, and effort with these factors being influenced at greater levels among female students. There is also evidence that the ways in which males’ and females’ self-efficacy beliefs are influenced by experiences (Hutchison-Green, Follman, & Bodner, 2008).

Although statistically significant differences in engineering self-efficacy were not found between males and females in a 2009 study, a statistically significant interaction between genders was indicated (Concannon & Barrow, 2009). This interaction was the result of women having significantly lower mean coping self-efficacy than their male counterparts. Concannon and Barrow (2009) point to the lack of statistically significant differences in mean engineering self-efficacy scores as confirmation of other studies similar findings
including those of Lent et al. (1986) and Schaefers, Epperson, and Nauta (1997). Concannon & Barrow (2009) directly repudiates (Bradburn, 1994) findings that female engineering majors have significantly lower levels of self-efficacy beliefs than males. Confirming these findings, Buse, Bilimoria, & Perelli (2013) found that female engineers who stay in the field expressed higher levels of self-efficacy than did those women who left engineering.

The identification and quantification of the self-efficacy beliefs of female engineering students may help to understand better the gender differences in that context. Self-efficacy has a clear impact on the academic persistence of female engineering students (Marra, Rodgers, Shen, & Bogue, 2012). Discovering trends in female students’ self-efficacy levels may serve to increase achievement and persistence within engineering graphics education. Currently, there are no data available for gender differences in self-efficacy within engineering graphics education. This research will add to the discussion and discourse into the gender differences in self-efficacy beliefs in engineering education.

**Theoretical Foundation**

Self-efficacy is a mediating factor for the behavior of an individual, which in turn, influences their performance (Bandura, 1977; Bandura, 1997). As a personal factor of social cognitive theory, self-efficacy refers to a person’s confidence in his or her ability to muster the requisite intrinsic resources necessary for successful task completion (Stajkovic & Luthans, 1998). The identification of self-efficacy as a personal factor within social cognitive theory is further supported by Bandura’s characterization and reference to self-efficacy as “people’s judgements of their capabilities…” (Bandura, 1986, p. 391) and those beliefs being
central to the mechanism of personal agency (Lent et al., 1984; Wood & Bandura, 1989). Self-efficacy beliefs are recognized as having strong predictive validity concerning achievement outcomes (Bandura, 1997; Pajares, 1996). These beliefs are also commonly understood to be domain and task specific (Blomquist, Farashah, & Thomas, 2016; Luszczynska, Scholz, & Schwarzer, 2005). Within the construct of self-efficacy are four fundamental factors: (a) experience or mastery experience, (b) modeling or vicarious experience, (c) social persuasion, and (d) physiological factors (Bandura, 1995).

**Social cognitive theory.** Bandura’s social cognitive theory explores how cognitive, behavioral, personal, and environmental factors interact and determine motivation and behavior (Crothers, 2008). Social cognitive theory suggests that parts of an individual’s knowledge acquisition are influenced by social interactions, social observation, outside influences (media, etc.), and experience (Bandura, 1989; Bardach, Gayer, Clinkinbeard, Zanjani, & Watkins, 2010).

Behavior is frequently described as having unidirectional causation and described as being shaped and controlled by either environmental influences or behavioral dispositions (Bandura, 1989). Social cognitive theory uses a model of triadic reciprocal determinism in which “behavior, cognition and other personal factors, and environmental influences all operate as interacting determinants that influence each other bidirectionally” (Bandura, 1989, p. 2) (Figure 6.2). These factors do not necessarily have equal influence, and one may exert greater influence on behavior and motivation, and factors and influences may not occur concurrently (Bandura, 1989).
Figure 6.2. Model of Triadic Reciprocal Determinism Based on (Bandura, 1989).

Self-efficacy is identified as a personal factor of social cognitive theory and refers to a person’s confidence in his or her ability to muster the requisite intrinsic resources necessary for successful task completion (Stajkovic & Luthans, 1998). The identification of self-efficacy as a personal factor within social cognitive theory is further supported by Bandura’s characterization and reference to self-efficacy as “people’s judgements of their capabilities…” (Bandura, 1986, p. 391) and those beliefs being central to the mechanism of personal agency (Lent et al., 1994; Bandura 1989). Self-efficacy exists within the individual’s internal locus of control (Bandura, 1977; Rotter, 1990).

**Self-efficacy, academic achievement, and persistence.** A student’s ability to successfully complete academic tasks is a direct result of his or her performance. This
performance is mediated by the student’s confidence in his or her ability to summon the needed cognitive, motivational, and actional resources for successful task completion within that specific context, or self-efficacy (Bandura, 1997; Stajkovic & Luthans, 1998). Self-efficacy is known to be domain and task specific and is not considered to apply to general topics and subjects, but rather, considerably more specific judgements about one’s capabilities (Linnenbrink & Pintrich, 2003). The specificity of self-efficacy measures is an important consideration as self-efficacy is a predictive factor for student performance (Zimmerman, 2000).

Zimmerman (2000) contends that self-efficacy beliefs correlate with domain-specific self-concepts; however, measurement of student levels of domain-specific self-concept beliefs do not have the same predictive validity as self-efficacy beliefs. For example, a domain-specific self-concept related to a general belief about competence such as understanding the engineering design process does not have the predictive ability of the self-efficacy belief related to evaluating and testing a design (Carberry, Lee, & Ohland, 2010).

Along with research supporting the mediation effect of self-efficacy beliefs on academic performance and goal attainment, these beliefs have been found to have this effect on attainment due to their influence on effort, persistence, and perseverance (Pajares, 1997). Figure 6.3 displays a model for the influence of self-efficacy beliefs and outcome expectations on performance, persistence, and academic goal attainment within the context of triadic reciprocal determinism (Bandura, 1989) and the self-efficacy models described by Bandura (1977) and Lent, Brown, and Hackett (1994).
Regardless of academic performance, students must remain in school and their academic programs to obtain degrees and be considered to have successfully completed a course of study. Their ability to persist through a university degree program is impacted by several factors including their levels of self-efficacy in the varied domains encountered in the normal course of a university degree program and its constituent courses. As one of these factors, self-efficacy is associated positively with persistence as well as academic performance (Fantz et al., 2011; Pajares, 1997). The understanding and prediction of vocational choice, academic achievement, and other career-relevant behaviors are known contributions of individual’s level of self-efficacy (Multon, Brown, & Lent, 1991). As there is an abundance of evidence that self-efficacy is positively associated with educational attainment and persistence (Bandura, 1997), there is also significant evidence that self-
efficacy levels significantly impact the academic attainment levels for both male and female undergraduate students (Raelin et al., 2014).

**Self-Efficacy Measurement**

One focus, and a research question in this study is to investigate whether or not significant differences exist between male and female students’ self-efficacy scores in an introductory engineering graphics course. Long standing beliefs and research trends have supported the findings that to have predictive validity, self-efficacy scales must be domain specific (Bandura, 2006; Lent et al., 1986; Zimmerman, 2000). To this end, an eight-item domain-specific three-dimensional modeling self-efficacy instrument was developed. These questions are answered using a seven-point Likert scale with one indicating “lowest agreement” and seven indicating “highest agreement.”

1. I feel that I am good at visualizing/manipulating 3-D objects in space.
2. I have confidence in my ability to model 3-D objects using computers.
3. I am confident enough in my 3-D modeling to help others model 3-D objects.
4. I am good at finding creative ways to model 3-D objects.
5. I believe I have the talent to do well in 3-D modeling.
6. I feel comfortable using 3-D modeling software.
7. I feel confident in my ability to create 3-D objects in a variety of ways.
8. I feel I can communicate 3-D objects to other peers.

*Figure 6.4. The Three-Dimensional Modeling Self-Efficacy scale.*

**Research Questions**

Using prior research findings that female engineering students perform academically as well as their male counter parts but have lower levels of self-efficacy (Godwin et al., 2016), this study seeks to determine if this trend holds true in engineering graphics – a
required course in many engineering programs – and what differences exist within this context. The following questions guided this research:

**RQ1.** Do statistically significant differences exist between male and female students’ academic outcomes (final course, project, and exam grades) in an introductory engineering graphics course?

**RQ2.** Do statistically significant differences exist between male and female students on a Three-Dimensional Modeling Self-Efficacy assessment in an introductory engineering graphics course?

**Methods**

**Participants and setting.** Participants in this study are undergraduate students at a large land-grant university in the southeastern United States. Participating students are enrolled in an introductory engineering graphics course. The course is taught in a large group instructional setting with 5-6 sections taught per semester and 40-60 students in each section. Students are primarily engineering majors, but the course is also offered for general credit and open to all students with no pre- or corequisites; however, this study is limited to those identified as majoring in engineering. Table 6.1 displays the demographic characteristics of the 578 students (479 male and 99 female) who participated in this study over the course of three consecutive semesters. Institutional review board (IRB) approval was sought and granted for research with this population.
Table 6.1

Demographic Information

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Female (n = 99)</th>
<th>Male (n = 479)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Percent</td>
</tr>
<tr>
<td>Asian</td>
<td>13</td>
<td>10.16%</td>
</tr>
<tr>
<td>Black or African American</td>
<td>3</td>
<td>2.34%</td>
</tr>
<tr>
<td>Hispanic or Latino</td>
<td>3</td>
<td>2.34%</td>
</tr>
<tr>
<td>American Indian or Alaska Native</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>Native Hawaiian or Other Pacific Islander</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>White</td>
<td>74</td>
<td>57.81%</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
<td>3.13%</td>
</tr>
<tr>
<td>Prefer not to answer</td>
<td>2</td>
<td>1.56%</td>
</tr>
<tr>
<td>Current status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freshman</td>
<td>35</td>
<td>27.34%</td>
</tr>
<tr>
<td>Sophomore</td>
<td>45</td>
<td>35.16%</td>
</tr>
<tr>
<td>Junior</td>
<td>13</td>
<td>10.16%</td>
</tr>
<tr>
<td>Senior</td>
<td>6</td>
<td>4.69%</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

Procedure

To address both research questions in this study, a post-test only quasi-experimental design was chosen for this study (Shadish, Cook, & Campbell, 2002). Near the end of each semester, course instructors gave their students a survey that included the Three-Dimensional Self-Efficacy scale and demographic questions. Instructors also provided the final course, project, and exam grades to the researcher. A total of 717 students participated in the survey.
The results of the self-efficacy scale, demographics, and grades were compiled, and the data were examined. Since this study focuses on women in engineering education, students who did not identify as engineering majors were not included. Likewise, nine students who marked “prefer not to answer” and one student who marked “other gender identity” were removed from the data set. This left 578 engineering majors who identified as male or female for comparison.

Operating under the premise that female students perform the same academically yet have lower levels of self-efficacy (Godwin et al., 2016), the researcher compared the average final exam, project, and course grades along with the students’ scores on the Three-Dimensional Self-Efficacy scale using Stata 14. T-tests were used to determine if significant differences existed between male and female students in the four metrics compared in this study. The following hypotheses were used in this research:

**Final course, project, and exam grades.**

H$_0$: There are no statistically significant differences in academic outcomes between male and female engineering students in an introductory engineering graphics course.

H$_1$: There are statistically significant differences in academic outcomes between male and female engineering students in an introductory engineering graphics course.

**Self-efficacy.**

H$_0$: Female students have significantly lower levels of self-efficacy than males in an introductory engineering graphics course.
There are no statistically significant differences in self-efficacy between male and female engineering students in an introductory engineering graphics course.

Comparison

Table 6.2 displays the means and standard deviations of the students’ final course, project, and exam grades, self-efficacy scores, as well as the results of the independent t-test results. It should be noted that the academic scores are out of 100 points and the self-efficacy scores are out of seven.

Table 6.2

Academic Outcome and Self-Efficacy Score Means, Standard Deviations, and T-Test results by Gender

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>Diff</th>
<th>Std. Error</th>
<th>t</th>
<th>df</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 479)</td>
<td>(n = 99)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final course grade</td>
<td>91.78</td>
<td>91.54</td>
<td>.24</td>
<td>.59</td>
<td>.41</td>
<td>576</td>
<td>.682</td>
</tr>
<tr>
<td>Final project grade</td>
<td>90.98</td>
<td>90.97</td>
<td>.01</td>
<td>.94</td>
<td>.00</td>
<td>576</td>
<td>.997</td>
</tr>
<tr>
<td>Final exam grade</td>
<td>88.96</td>
<td>88.25</td>
<td>.71</td>
<td>.86</td>
<td>.83</td>
<td>576</td>
<td>.041</td>
</tr>
<tr>
<td>Self-efficacy*</td>
<td>5.70</td>
<td>5.23</td>
<td>.47</td>
<td>.09</td>
<td>5.08</td>
<td>576</td>
<td>&gt; .001</td>
</tr>
</tbody>
</table>

*Three-dimensional modeling self-efficacy.

Academic Outcomes

As predicted, female engineering students performed as well academically as their male counterparts in final course grade and final project grade. There is a statistically significant difference in final exam grade with female students scoring .71 points, \( p < .05 \), lower on average than males. However, with this difference being less than a point and the
fact that there is no difference in course grade, there may be a legitimate question as to the meaningfulness of the difference in a single component of a course grade.

Self-Efficacy

This study is based on the assertion that female engineering students perform equally concerning academic tasks, but their self-efficacy levels do not reflect this parity. The female engineering students scores on the Three-Dimensional Modeling Self-Efficacy assessment were .47 points lower than males. This represents an 6.7% lower self-efficacy score. This significant difference, $p < .001$, reflects the contention of prior research (Godwin et al., 2016) and potentially confirms its existence in the sub-discipline of engineering graphics.

Discussion

Research into gender differences in engineering graphics have been a continuing point of discussion and the basis of several interventions directed at addressing skill and competency gaps at the university level (Sorby, 1999; Sorby & Baartmans, 2000; Sorby, Signorella, Veurink, & Liben, 2013). Self-efficacy research is commonplace in engineering (Chachra, Dillon, Spingola, & Saul, October 2014; Mamaril et al., 2016), but still burgeoning in engineering graphics (Metraglia et al., 2016). Confirming the existence and equivalence of trends related to non-cognitive metrics in engineering graphics is an important step and adds to the extant literature.

However, knowing that these differences exist is only the beginning of our understanding of the phenomenon in an engineering graphics context. The question remains: Why do these differences exist and what can be done to increase the recruitment, persistence,
and retention of women in engineering? Self-efficacy may offer insight into these issues and perhaps, if not a solution, possible mitigation to the causes of the engineering gender gap.

This study demonstrates that the academic and self-efficacy trends of women in engineering are also present in engineering graphics. As a fundamental component of many engineering programs of study, the field has an opportunity to address this issue in a manner and setting that reaches across many engineering sub-disciplines and potentially impact a greater number of women at risk of attrition in either their education or career paths.

The construct of self-efficacy and its four fundamental factors: (a) experience or mastery experience, (b) modeling or vicarious experience, (c) social persuasion, and (d) physiological factors (Bandura, 1995) is a known area where there are quantifiable differences between men and women. Since both this study and the extant literature demonstrate that it is not academic ability or performance, an exploration into why these differences exist in non-cognitive areas is crucial especially given the clear links between persistence and factors such as self-efficacy. Exploration into the reasons behind lower self-efficacy levels of women in engineering graphics courses is beyond the scope of this study which sought solely to confirm the existence of this disparity. Future research should focus on both the reasons for the lack of gender parity in self-efficacy levels within engineering graphics education and explore possible interventions that improve the self-efficacy levels of women in engineering graphics specifically with the intention of improving their participation and persistence in engineering education and careers generally.
Conclusion

There has been stagnant growth in the number of female engineers in the United States for several decades. This study identified trends related to gender in self-efficacy, and academic outcomes among engineering students are also present in engineering graphics education. Understanding the non-cognitive factors related to female persistence in engineering education is an important facet of knowledge if we are to meaningfully address the increasing demand for engineers and the substantial gender gap that exists in that field. This research presents evidence that lower levels of noncognitive factors exist among women in engineering graphics and is offered as a basis for future research and intervention development aimed at increasing female self-efficacy levels in engineering graphics and their persistence levels in engineering education and beyond.
References


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