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Developing a Scale to Investigate Student's Self-Efficacy as it Relates to Three-Dimensional Modeling

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Introduction

Binkley et al. (2012) contends that the economy and workplace for the 21st Century will not lie in the routine tasks of the past, instead emphasis will be put on the ability of students to communicate, share and use information to solve increasingly complex problems. This is especially true of individuals who chose to pursue careers in the sciences, technology, engineering, and mathematics (STEM). For many engineers and technologists, at the heart of this exchange of information is the ability to model, design, and fabricate complex objects using the latest three-dimensional modeling software. Yet, for many students tackling this authoring software begins with their own perceived ability to complete said task. Eccles et al. (1983) seminal research revealed that students' belief about their ability to complete a task is inextricably linked to their previous experience and other socialization factors. To better understand how different experiences impact students' belief about their abilities, it is imperative to design, test and validate instruments with the ability to provide insight into students' belief in their ability to complete a task within a given domain or self-efficacy. In an effort to address the lack of instruments designed to measure students' self-efficacy as it relates to three-dimensional modeling, researchers conducted a study with the intent to develop, test and validate such an instrument.

With more and more middle and high school STEM courses using of computer-aided design (CAD) software (a central component of engineering graphics education) to enhance instruction and incorporate 21st-century skills in the classroom (Katsioloudis & Jones, 2015; Schoembs, 2016), the effect of these programs on non-cognitive constructs such as self-efficacy represents a dearth in the contemporary literature. Technology and 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) is increasing students' exposure to CAD in the general education classroom (Schoembs, 2016; Standish, Christensen, Knezek, Kjellstrom, & Bredder, 2016). It is also becoming more common to see Makerspaces and Fablabs in K-12 schools, adding to the need for students to have at least a basic understanding of three-dimensional modeling and using CAD software.

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

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SketchUp can be used free with some limitations whereas full version access to the industry-standard Autodesk suite of CAD programs is 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.

A review of the extant literature on three-dimensional modeling and spatial skills reveal previous studies that have identified factors that impact student success in engineering graphics however much of their focus is on operational tasks that help build students' skill level such as sketching (Sorby, 1999a). Studies have also noted the impact of having students work with hand-held models and given voice to the ability of student's spatial ability to predict success in three-dimensional modeling (Sorby, 1999b). However, few studies have investigated the ability of affective measures to predict student success in three-dimensional spatial and visualization skills. The dearth of research investigating the impact of affective constructs on student success in three-dimensional modeling can in part be attributed to the lack of valid and reliable instruments that measure these constructs.

The goals of this study were to develop a valid and reliable instrument for the purpose of measuring students' self-efficacy as it relates to three-dimensional (3-D) modeling. Currently, there is not an instrument available that measures students' self-efficacy as it relates to three-dimensional modeling. Based on Bandura's Social Cognitive Theory, self-efficacy is a construct that has been measured in education for the last forty years (Bandura, 1977). Those familiar with measuring this construct are aware of its domain specificity. Bandura (2006) argues that, "there is not all-purpose measure of perceived self-efficacy" (p. 307). Sherer et al. (1982) offers that self-efficacy has been primarily thought of as a task-specific belief. Hence, in order to effectively measure self-efficacy as it relates to three-dimensional modeling, a scale must be developed specifically related to this domain. This approach is support by Sherer et al. (1982) who asserts that when dealing with specific behaviors, more direct behavioral measures will increase the accuracy of the measurement. Bandura (2006) helps bring this point home by proffering that self-efficacy scales must be tailored to activity domains in order to assess the multifaceted ways in which efficacy beliefs operate within the selected activity domain. In this study researchers present the results of a pilot study conducted for the purpose of testing the reliability of a scale design to measure students' self-efficacy as it relates to three-dimensional modeling.

There was one research question guiding this study;

1. Is the newly developed instrument for measuring students' self-efficacy as it relates to three-dimensional modeling a reliable instrument?

To answer this question researchers tested the newly developed self-efficacy instrument with middle school and high school students. In the next section, the researchers present a literature review in an effort to situate this study within context of the most current literature on self-efficacy and measuring three-dimensional modeling.

Literature Review

Self-Efficacy

Self-efficacy refers to the confidence in one's ability to successfully complete a given task in order (Bandura, 1977, 1997). Self-efficacy is rooted in Social Cognitive Theory, which holds that knowledge acquisition is directly related to observing others within their context of social interactions, experiences, and outside media influences (Bandura, 1988). A student's self-efficacy levels help mediate their behavior. Their behavior, in-turn, influences their academic outcomes. 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 for success in these fields (Zeldin, 2008).

Self-efficacy has also been shown to be positively associated with performance among engineering graphics students (Metraglia, Villa, Baronio, & Adamini, 2016), and has been identified as having a significant impact on the educational outcomes and persistence in academic settings (Bandura, 1997; Lent, Brown, & Larkin, 1984; Pajares, 1996). 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 the self-efficacy beliefs of engineering students significantly and, by extension, their choices to pursue and persist in engineering careers (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, 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.

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 significantly increase the self-efficacy beliefs of college engineering students and, by

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extension, their choices to pursue and persist in engineering (Fantz, Siller, & Demiranda, 2011). The greatest contributing factor to a student's self-efficacy levels are mastery experiences (Bandura, 1997) which engineering graphics courses provide opportunity for through hand-on experiences and project-based assignments. Research has consistently supported the assertion that in order to have to be an adequate predictor of student performance, self-efficacy scales must be domain specific (Lent et al., 1986; Zimmerman, 2000).

In engineering education, a student's self-efficacy levels have been demonstrated to be a predictor of achievement and persistence (Loo & Choy, 2013). 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 significantly increase the self-efficacy beliefs of college engineering students and, by extension, their choices to pursue and persist in engineering (Fantz, 2011). The greatest contributing factor to a student's self-efficacy levels are mastery experiences (Bandura, 1997) which engineering graphics courses provide opportunity for through hands-on experiences and project-based assignments. Research has consistently supported the assertion that in order to have to be an adequate predictor of student performance, self-efficacy scales must be domain specific (Lent, 1994; Sherer, 1982).

Three-Dimensional Modeling

The development of a scale to measure self-efficacy must clearly define its respective domain; in this case three-dimensional modeling. Students most often encounter modeling in engineering design challenges through hands-on experiences. Often, this end product is modeled before final production for testing and evaluation commences. A model can be a tangible prototype, simulation, or procedure. This study is concerned with graphical model representations. It is vital that this study clearly differentiates graphical modeling from other forms of modeling. A graphical model is principally representational. This particular model is usually shared among design team members in order to solidify the details of the design. This design will take on dimensions and interfaces will be defined. At this point in the design process feasibility is often determined. Therefore, this model contains dimensions, clear specifications, and more accuracy. This model may be termed hard-lined, as it is more concrete in its form (MacDonald, Gustafson, & Gentilini, 2007). A graphical model is one that is typically — though not always — generated with some form of software on a computer. This allows for simulation and testing transitioning into other models for analysis.

Although scales for self-efficacy exist for engineering and engineering education, there are currently no existing domain-specific scales for engineering graphics or three-dimensional modeling. To this end, we are concerned with students' ability to model objects in a three-dimensional space and the development and psychometric analysis of a domain-specific instrument intended to measure three-dimensional modeling self-efficacy.

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Methods

The survey instrument framing this study was developed by modifying and building upon instruments used in prior studies. Specifically, the scale was grounded in the work of Bandura, especially his “Guide for Constructing Self-Efficacy Scales” and his Self-Efficacy Beliefs of Adolescents (Bandura, 2006). The format of the instrument used in this study closely resembles the evaluation survey created by The New Traditions Project. Marat (2005) developed an instrument that measured mathematics self-efficacy for students learning in a multicultural environment of which the results are provided in *Assessing Mathematics Self-efficacy of Diverse Students from Secondary Schools in Auckland*. Using existing questionnaires and literature that examined the intended constructs, an instrument was drafted by the researchers.

In this instance, it was necessary to modify questions so that they related specifically to the modeling of three-dimensional objects, which was a focus of the instrument. In order to achieve face validity for self-efficacy scales, Bandura (2006) contends that self-efficacy scales should measure what they purport to measure. Face validity was seen as an appropriate method of validity and is viewed as a proven measure of the quality of a test and can be verified statistically (Bandura, 2006). The face validity, which details a scale’s adherence to a cogent construct, is achieved only after a reasonable level of agreement exists among raters (Nevo, 1985). Researchers for this study collaborated with subject matter experts (SME) in graphics communication at a research one institution in an effort to modify the existing items to better measure the desired construct. It is imperative that researchers secure SMEs with similar backgrounds and more importantly, a displayed expertise in the domain of functioning.

Researchers were able to secure three experts in the field who each touted over a decade of experience in teaching engineering design graphics at the secondary and tertiary level, experience designing state curriculums focused on engineering design graphics and experience in designing and validating psychometric scales. Each expert reviewed the formative instrument individually and provided comments in regards to the appropriateness of the items as they related to the construct of interest. Items that were considered problematic and did not achieve face validity were removed or revised based on recommendations from the SEMs. The final instrument was returned to the experts for their final approval. The resulting instrument, according to face validation, measured the desired constructs that framed this particular study. The final instrument was not decided upon until consensus had been met amongst the subject matter experts and the researchers.

Pilot Test

Participants were 101 middle school and high school students who were participating in a mathematics, science, and engineering Summer camp held at a research-intensive

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university in the Southeast. The results reported are from 91 participants. Ten (10) of the surveys collected were deemed invalid and were not used in the study.

Results

The resulting instrument was a nine-question questionnaire that was devised to measure students' self-efficacy as it relates to modeling three-dimensional objects (see appendix). Each question was a 7-point Likert type item from "highest level of agreement" to "lowest level of agreement." In order to understand whether the questions all reliably measure the same latent variable (self-efficacy to model three-dimensional objects), Cronbach's alpha was run as a test of internal consistency.

The reliability of the test was evaluated using Cronbach's alpha statistic. Stability, based on test-retest, indicates the degree to which scores on the same instrument are consistent over time. To evaluate the reliability coefficient the scores of the pilot test were correlated. Values ranging from 0.70 to 0.95 are considered to be sufficient to consider an instrument reliable (Drost, 2011).

Results from reliability tests yielded a Cronbach's Alpha of .7 or higher for all nine (9) items in the self-efficacy survey and the overall Cronbach's Alpha for the scale is .815 indicating a high level of internal consistency.

Table 1
Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Square Multiple Correlation	Cronbach's Alpha if Item Deleted
Q1	36.85	73.601	.451	.222	.804
Q2	37.12	69.302	.559	.488	.791
Q3	37.70	69.432	.586	.377	.788
Q4	37.09	70.414	.489	.332	.800
Q5	36.53	73.685	.464	.268	.803
Q6	37.33	68.638	.536	.508	.794
Q7	37.28	67.799	.655	.512	.780
Q8	37.43	68.615	.560	.408	.791
Q9	37.17	75.037	.330	.223	.819

Conclusions/Discussion

Spatial visualization is viewed by many in the engineering graphics community as the "most fundamental" aspect of engineering graphics communication (Katsioloudis, 2014). Subsequently, this suggests that the ability to model objects in a three-dimensional space particularly for students aiming to pursue careers in STEM areas is paramount.

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The research is clear when discussing the relationship between self-efficacy and students' participation in STEM related tasks however there is little to no research which looks at the relationship between students' self-efficacy and its relationship with student outcomes.

This research begins a thematic endeavor for the authors focused on the investigation of different methods of assessment for students in engineering graphics and visualization courses. To improve pedagogical practices within the classroom adequate measures must be developed in order to support teaching practices. The results from this study will inform further investigation into students' self-efficacy as it relates to three-dimensional modeling. The literature is demonstrative in its assertion that an instrument to measure self-efficacy would need to be domain specific (Bandura 1997, Sherer et al., 1982). Results from this study provided evidence that the scale developed was a reliable instrument. Further research includes targeting a larger sample population in an effort to perform an exploratory factor analysis on the eight remaining items.

The literature is replete with visualization tests for the measuring of students' three-dimensional modeling ability. Yet, little research links students' spatial visualization ability and their ability to persist, and complete a task. Self-efficacy has been shown to be a predictor of success and persistence in STEM fields, particularly for students from underrepresented populations (Zeldin, 2008). Designing experiences and activities that positively impact students' self-efficacy can potentially help attract underrepresented students to STEM areas. Yet, it is a nebulous task when attempting to determine experiences that positively impact students' self-efficacy. Developing measures that can accurately pinpoint and isolate this domain-specific construct will provide instructors with tools necessary for evaluating the value and impact of their lessons and activities. As instructors look for innovative ways of engaging their students, it may behoove of them to direct their attention to more affective measures.

Although the instrument was able to achieve face validity according to the SMEs, more nuanced investigations are needed in order to achieve content or construct validity. For self-efficacy scales to be effective it is imperative that they are domain specific. Bandura (2006) proffers that initially, self-efficacy scales should have face validity, but they should also display discriminant validity and predictive validity as well. Researchers suggest that self-efficacy beliefs should be distinguishable from related constructs such as self-esteem, and outcome expectations (Bandura, 2006). However, tests of this nature were outside the scope of this research study. In furthering the development of the self-efficacy scale, the researchers are interested in conducting an exploratory factor analysis in an effort to ensure the homogeneity of the constructed items.

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