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Volume XLVI, Number 2, Fall 2020

Reliability and Validity for a 3-D Modeling Self-Efficacy Scale for Pre-College Students

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ABSTRACT

Engineering graphics education has long been a required component of technology and engineering education at the university level. In middle and high schools, the number of computer-aided design (CAD) programs continue to proliferate and grow. Lacking in the research related to these programs is the effect on non-cognitive factors such as self-efficacy. Self-efficacy is a predictor of success and perseverance and is an important consideration in technology and engineering education. This research investigates the psychometric properties of an instrument designed to measure the three-dimensional modeling self-efficacy among middle and high school students.

This study found the Three-Dimensional Modeling Self-Efficacy Scale to be a reliable measure within this population with strong evidence of validity. Based on these findings, the scale was revised, and recommendations for future study were made. This research begins to fill a gap not only in research related to engineering graphics self-efficacy but also within a pre-college population, especially those who are historically underrepresented in engineering disciplines, in this case, female students.

Keywords: *self-efficacy, technology education, engineering education, computer-aided design (CAD), three-dimensional modeling*

INTRODUCTION

Middle and high school STEM courses are seeing increased use of computer-aided design (CAD) software to enhance instruction and to incorporate 21st-century skills in the classroom (Katsioloudis & Jones, 2015; Schoembs, 2016). High school 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 at least be 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 three-dimensional (3D) fabrication technologies become more popular and commonplace.

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 as a powerful contributor to students' career decisions, as well as a predictor of success in technology and engineering education and career pathways (Zeldin, Britner, & Pajares, 2008).

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, this research adds to the growing body of work on self-efficacy in technology and engineering education contexts by introducing preliminary work on a self-efficacy instrument solely focused on three-dimensional modeling (Denson, Kelly, & Clark, 2018). This study addresses the need for more research focused on investigating the impacts of affective constructs on student success in coursework and career pathways that include engineering graphics or CAD as important components by reporting on the validity and reliability of a three-dimensional self-efficacy instrument.

RESEARCH QUESTIONS

RQ1: Does the domain-specific Three-Dimensional Modeling Self-Efficacy scale provide evidence of reliability among middle and high school student populations?

RQ2: Does the domain-specific Three-Dimensional Modeling Self-Efficacy scale provide evidence of validity among middle and high school student populations?

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

RQ2: 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

The Three-Dimensional Modeling Self-Efficacy (3DSE) scale used in this study was developed by modifying and building upon instruments used in prior studies (Denson, Kelly, & Clark, 2018; Kelly, 2020; Kelly, Ernst, & Clark, 2019). Development of the 3DSE 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 (SMEs) in graphics communication at a research-intensive, land-grant institution to confirm the existing items were associated with engineering graphics/CAD. The SMEs provided comments and feedback, which were incorporated into the scale design. The SMEs and researchers were in consensus that the resulting instrument measured the desired domain of three-dimensional modeling, which framed this particular study and achieved face validity. Face validity 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). The nine-items of the 3DSE scale developed for use in this study are shown below. 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.

Participants

This study was conducted during a summer camp with a technology and engineering focus 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 week-long experience. Males represent approximately 63% of the sample population ($n = 57$) and females represent 37% ($n = 34$). Middle school students represent approximately 47% of the sample population (n = 41), and high school students represent 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 the self-efficacy scale used in this study is valid, researchers 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's rather than expert(s)' opinion and differs from content validity in that it 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 within an observed set of variables (Burton & Mazerolle, 2011). Ultimately, EFA is used as a means not only to 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 adequacy of the sample was evaluated. 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 sample in this case ($n = 91$) was adequate. Next, the sampling adequacy was assessed to determine if the inter-item correlations are suitable for EFA (Burton & Mazerolle, 2011). An examination of the instrument's 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 total variance extracted column in the factor output table was inspected, 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 for (Beavers et al., 2013). Since no "best" method exists, it is incumbent upon the researcher(s) to carefully consider these methods and use an *a priory* understanding of the theory underpinning this study to determine how best to 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 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 were less than .40.

Differences in the three-dimensional modeling self-efficacy levels between male and female students and those students in middle or high school were examined. These comparisons were made using analysis of variance (ANOVA). Evidence of significant correlations between levels of three-dimensional modeling self-efficacy and gender and grade level were assessed.

FINDINGS

Descriptive statistics and tests for normality (skewness and kurtosis) are displayed in Table 1. Stata 14 was used to analyze the data in this study.

Reliability

The reliability of the 3DSE scale was determined using Cronbach's alpha statistic to address the first research question. The nine-item 3DSE scale was determined 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, it was first determined whether the 3DSE 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 was 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 3DSE scale and addressing the third research question, an exploratory factor analysis was conducted. The initial step in EFA is to determine the adequacy of the sample. To accomplish this, three methods of analysis were used: examination of the correlation matrix, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, and Bartlett's test of sphericity. Table 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).

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 ($\chi2$ (36) = 233.452, $p < .001$), indicating the

Table 1. Descriptive statistics and tests for normality for the Three-Dimensional Modeling Self-Efficacy scale, $n = 90$.

Item	*M*	*SD*	Skewness	Kurtosis	chi2	*p*-value
1	4.85	1.52	.01	.95	**6.60**	0.037
2	4.66	1.68	.29	.00	**11.73**	0.003
3	4.15	1.58	.57	.12	2.87	0.238
4	4.68	1.73	.35	.00	**8.54**	0.014
5	5.23	1.47	.00	.30	**9.54**	0.009
6	4.48	1.82	.43	.00	**11.02**	0.004
7	4.59	1.59	.10	.10	5.34	0.069
8	4.40	1.74	.11	.03	**6.55**	0.038
9	4.73	1.70	.01	.86	**7.05**	0.030
Mean	4.65	1.04	.20	.90	1.73	0.451

Note. Values in bold are significant at $p < .05$ level.

Table 2. Intercorrelations for Items in the 3D Modeling Self-Efficacy Scale

Item	1	2	3	4	5	6	7	8	9
1	-								
2	**.38**	-							
3	**.33**	**.49**	-						
4	.21	.20	**.33**	-					
5	**.22**	**.22**	**.24**	**.39**	-				
6	**.37**	**.63**	**.40**	.16	**.32**	-			
7	**.41**	**.45**	**.43**	**.41**	**.41**	**.53**	-		
8	**.32**	**.27**	**.40**	**.40**	**.31**	**.23**	**.50**	-	
9	**.27**	.07	**.24**	**.30**	.18	.07	.11	**.39**	-

Note. Coefficients in bold are significant at $p < .05$ level.

sample was not an identity matrix. These two measures, combined with the analysis of the correlation matrix, support the 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 3DSE scale. The results of the EFA for the nine-item scale can be found in Table 3.

Using Kaiser's criterion, factors with eigenvalues greater the 1.00 were retained (Yong & Pearce, 2013). To confirm this method, the total variance explained was examined. 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 3DSE scale. The single-factor solution is displayed in Table 4.

Item Retention.
Analysis of the factor loadings of the scale items indicated that item nine had both remarkably lower factor loading and communality values. As a result, the text of item nine (I always understand what 3D images are trying to communicate) was examined and determined it related to the subject's understanding rather than a belief in their ability to complete a task or "do." Based on this and the low factor loading and communality values of item nine, it was removed from the 3DSE scale.

Eight-Item Scale

To examine the eight-item 3DSE scale's psychometric properties, the same methods and analyses used for the nine-item scale were used. The eight-item 3DSE scale was determined to be reliable (α = .81) with a greater average inter-item covariance (.96) than the nine-item version (.87). Table 5. displays the single-factor solution for the eight-item 3DSE scale.

The single-factor underlying the eight-item 3DSE 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 3DSE scale (eight-item) and the participant's gender (r = .13, p = .203) nor between score and grade level (r = -.03, p = .768). Neither gender nor 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 3DSE scale. The results also support the removal of item nine in the instrument resulting in an instrument that appears to measure the construct of three-dimensional modeling self-efficacy better and is slightly more parsimonious. The following results help advance knowledge of research situated in technology and engineering education contexts and contributes to the body of work focused on the development of self-efficacy instrumentation.

Table 3. Factor Loadings from Exploratory Factor Analysis: Uniqueness, Eigenvalues, and Percentages of Variance for the Three-Dimensional Modeling Self-Efficacy Scale (9-Item)

	Factor Loading			
Item	**1**	**2**	**3**	**Communality**
1	.54	-.03	.16	.33
2	.64	-.38	.11	.57
3	.62	-.03	.15	.43
4	.51	.34	-.13	.40
5	.49	.14	-.24	.32
6	.65	-.41	-.03	.59
7	.74	-.04	-.21	.61
8	.61	.32	.05	.48
9	.34	.39	.24	.33
Eigenvalue	3.05	.70	.23	
% of Variance	90.41	20.78	7.06	

This is particularly important due to noted positive relationships between self-efficacy beliefs, academic success, and student choice to pursue and persist in fields in which engineering graphics and CAD are integral components (Fantz, Siller, & Demiranda, 2011).

Of particular interest in the results of this study was the lack of difference in self-efficacy levels between males and female participants. Current research suggests that females generally have lower levels of self-efficacy than do males in engineering and related contexts (Godwin, Potvin, Hazari, & Lock, 2016). The lack of difference, in this case, 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 diverge from males during tertiary 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 researchers, which led to these differences. It must be noted that student participants in this study were part of an engineering and technology education, which may speak to higher levels of self-efficacy for all participants. Regardless, more research is needed in this area and preferably with different populations.

CONCLUSION

The eight-item 3DSE scale is currently the only known instrument that relates explicitly to engineering graphics education. This research found the 3DSE scale to demonstrate evidence of reliability and validity for the population studied. However, there are differences related to gender that need greater study and explanation. More research 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.

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Table 4. Single-Factor Loading from Exploratory Factor Analysis: Uniqueness, Eigenvalues, and Percentages of Variance for the Three-Dimensional Modeling Self-Efficacy Scale (9-Item) Efficacy Scale (9-Item)

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

Table 5. Single-Factor Loading from Exploratory Factor Analysis: Uniqueness, Eigenvalues, and Percentages of Variance for the Three-Dimensional Modeling Self-Efficacy Scale (8-Item)

Item	Factor loading	Uniqueness
1	.53	.72
2	.66	.56
3	.62	.61
4	.48	.76
5	.49	.76
6	.67	.55
7	.75	.43
8	.57	.67
Eigenvalue	2.92	
% of Variance	98.26	

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