Journal for Geometry and Graphics
Volume 24 (2020), No. 1, 125–140.

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

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Abstract. Self-efficacy positively mediates performance, persistence, and academic outcomes, and its measures are known to have strong levels of predictive validity in educational environments. Although investigations into self-efficacy are present in engineering education, there are few studies within the sub-discipline of engineering graphics. Self-efficacy researchers are consistent in the literature that measures of the construct must be domain-specific. To date, little examination into a self-efficacy instrument specific to engineering graphics exist. This study investigates the psychometric properties of the Three-Dimensional Modeling Self-Efficacy instrument specifically developed for engineering graphics and presents the methods and findings of a psychometric investigation of that instrument using a population of 503 undergraduate students enrolled in an introductory engineering graphics course. This investigation includes reliability metrics, correlational analysis, exploratory factor analysis, and regression analysis. The Three-Dimensional Modeling Self-Efficacy instrument examined in this study was found to have strong evidence of reliability and validity, and exploratory factor analysis revealed a single factor structure underlying the instrument. The Three-Dimensional Modeling Self-Efficacy instrument also appears to have evidence of predictive validity for student final course outcomes.

Key Words: engineering graphics, self-efficacy, three-dimensional (3D) modeling, engineering education

MSC 2010: 97G80

1. Introduction

Engineering graphics is a required area of study for many engineering programs, and these courses have some of the highest enrollment in STEM education [30]. Although not specifically engineering, literacy in engineering graphics communication is necessary for success in

ISSN 1433-8157/$ 2.50

engineering professions. Engineering education's long history of utilizing graphics linguistically continues to be the preferred method for the communication of designs and ideas [7, 9]. With the rise of computer use to near ubiquitous levels 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 [6].

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 which adds, "with a variety of audiences" (Accreditation Board for Engineering and Technology) [1]. Despite there not being a 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 graphics 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.

A major component of modern engineering graphics courses is the use of computer-aided design (CAD) software. A recent study of university-level engineering graphics instructors found that nearly 95% of these courses required the use of CAD software as part of the course [32]. Further, the same study found the ability to visualize and create three-dimensional solid computer models were objectives in 77 and 72 percent of courses, respectively. Sutton et al. [32] also noted that greater than half of the students' final course grades were determined by their technical ability of which CAD-derived artifacts were required in nearly all of the courses studied. Of the top four work types assessed in these courses, computer generated assemblies (90%), computer-generated engineering drawings (69%), and computer-generated 3D models (69%) are represented with only technical sketching being more prevalent (92%). Digitally fabricated models, which still require the use of three-dimensional modeling software to create, were the next highest type of assessment, with only 15% of courses requiring them.

Provided the prevalence of CAD in these courses and the extensive use of three-dimensional modeling software within these courses, it is important that educators, instructional designers, and researchers understand all of the relevant cognitive and non-cognitive factors that might impact student learning and achievement with respect to such a common component of engineering education. Self-efficacy, as a known influencer of academic performance [20], is one such non-cognitive factor. This study examines the psychometric properties of a self-efficacy instrument purported to be designed for three-dimensional modeling.

2. Self-efficacy in Engineering Education

Self-efficacy refers to a person's belief in his or her ability to muster the requisite intrinsic resources necessary for successful task completion [31]. 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 judgments of their capabilities" [2] and those beliefs being central to the mechanism of personal agency [3, 19].

Self-efficacy, as a known mediating factor between behavioral dispositions, cognition, and behavior that, in turn, influences the academic performance of a student [20]. 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 [28]. Self-efficacy has also been shown to be positively associated with performance among introductory engineering graphics students [24, 25].

A student's ability to 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 [4, 31]. 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 judgments about one's capabilities [21]. The specificity of self-efficacy measures is an important consideration as self-efficacy is a predictive factor for student performance [38].

Zimmerman [38] contends that self-efficacy beliefs are correlated 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 [12]. 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 [28].

Self-efficacy has been shown to be positively associated with performance among introductory engineering graphics students [25], and as having a significant impact on the educational outcomes and persistence in academic settings [4, 20, 28]. Self-efficacy has also been identified as a predictor of achievement and persistence among engineering students [22, 29]. In addition to the positive relationship between self-efficacy beliefs and academic success and persistence generally, an individual's level of self-efficacy beliefs in engineering domains is known to be significantly associated with the academic outcomes of college engineering students specifically and, by extension, their choices to pursue and persist in engineering [16].

There exists a body of evidence that self-efficacy plays a significant role in predicting student outcomes and persistence in engineering education classes. Significant associations have been found between self-efficacy and academic outcomes with regression analysis suggesting that self-efficacy beliefs contribute a significant amount of unique variance toward the prediction of student academic outcomes [20, 35]. This research continues to confirm the positive association between self-efficacy and student academic outcomes. Contemporary 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 [23] 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 self-efficacy levels.

3. Research questions

There is a lack of domain-specific instrumentation to examine self-efficacy within the field of engineering graphics. This study builds on two previous investigations into the psychometric properties of a Three-Dimensional Modeling Self-Efficacy (3DSE) scale specific to a fundamental proficiency within the domain of engineering graphics [14, 13]. The following questions guided this research:

1. What is/are the underlying latent constructs for the items in the domain-specific 3DSE scale?
2. Is there evidence of validity in the domain-specific 3DSE scale?
3. What effect does a student's 3DSE have on their academic outcomes in an undergraduate introductory engineering graphics course?
4. Is there evidence of reliability in the domain-specific 3DSE scale?

4. Methods

4.1. Participants and setting

Participants in this study were undergraduate students at a large, land-grant university in the southeastern United States. Participating students were 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 were primarily engineering majors (nearly 60% were mechanical engineering majors), but the course is also offered for general education credit and open to all students with no pre- or co-requisites. Table 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.

The course is 15 weeks long and covers sketching, engineering geometry, orthographic and pictorial projection, working drawings, dimensioning, assemblies, and section and auxiliary views. Much of the coursework uses solid modeling (using SolidWorks) with 12 of 20 assignments, multiple quizzes, and a final project requiring students to be able to model 3D objects. Students also have the opportunity to take a SolidWorks professional certification exam after they complete the course. The remaining content is divided between hand drawing (mainly orthographic and isometric), engineering graphics theory, and standards and conventions. The final exam is 100 question, content-specific, multiple choice assessment of all content covered thought the semester.

4.2. Instrumentation

No single instrument can measure an individual's perceived self-efficacy due to the task-specific nature of self-efficacy [5]. Prior to this study, an instrument to measure students' self-efficacy as it relates to three-dimensional modeling was developed [14]; however, little psychometric analysis was performed. As a construct of great importance to the engineering graphics and engineering education communities, it is essential that any instrument used be able to demonstrate evidences of reliability and validity.

The Three-Dimensional Modeling Self-Efficacy (3DSE) instrument used in this study is a 8-item instrument that includes a seven-point Likert-type scale from highest level of agreement to lowest level of agreement. The instrument originally consisted of 9 items; however, an item was removed after a previous psychometric analysis [13] found that the item was poorly worded and did not represent the construct in question. The 8-item revised scale is below:

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.

Table 1: Demographic characteristics of participants ($n = 503$)

		n	%
Gender	Male	408	81.11
	Female	87	17.30
	Other gender identity	1	0.20
	Prefer not to answer	7	1.39
Race/Ethnicity	American Indian or Alaska Native	2	0.40
	Asian	56	11.13
	Black or African American	16	3.18
	Hispanic or Latino	20	3.98
	Native Hawaiian or Other Pacific Islander	3	0.60
	White	373	74.16
	Other	17	3.38
	Prefer not to answer/No answer	16	3.18
Class Standing	Freshman	184	36.58
	Sophomore	209	41.55
	Junior	72	14.31
	Senior	31	6.16
	Other	7	1.39
Major	Engineering	413	82.11
	Other STEM	92	12.52
	Other	55	10.93
	None	13	2.58
Engineering Major (Matriculated)	Mechanical	244	58.51
	Aerospace	62	14.87
	Civil	8	1.92
	Textile	28	6.71
	Electrical/Computer	11	2.64
	First year Engineering Program	14	3.36
	Other Engineering Major	12	2.88
	Engineering (Major not specified)	31	7.43

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 I can communicate 3D objects to other peers.

The 3DSE instrument was chosen based on its general discussion of 3D modeling rather than a reliance on specific standards or program functioning. In this line of inquiry, we are not interested in students' particular levels of content of software knowledge, but rather their belief in their abilities to communicate in a 3D CAD context.

The broad nature of the concepts, principles, standards, conventions, and software complexities related to three-dimensional modeling make a single instrument that covers all of these concepts difficult to develop as differences in these areas and changes over time to standards and software would require constant revision of the instrument. As such, this study is focused on 3D modeling as a means of communicating graphically within an CAD context.

4.3. Validity

To address the second research question, whether or not the 3DSE instrument demonstrates evidence of validity in this study, the items in the instrument were examined to first determine if the 3DSE demonstrated evidence of 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 [36]. Although subjective and often viewed as a weak form of construct validity [15], face validity was included to support the assertion that the instrument is appropriate for measuring the construct of 3D modeling self-efficacy [36]. 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 [17]. Face validity is ultimately a subjective judgment of the researcher(s) regarding instruments used [15] 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 3DSE 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 3DSE scale [17].

Lastly, evidence of discriminant validity was determined by comparing the relationship between the students' scores on the 3DSE scale to the students' scores on the Self-Efficacy of Learning (SEL) instrument [17]. Since, theoretically, self-efficacy instruments need to be domain specific [5], a comparison of these two instruments should show low or non-existent correlations between them.

4.4. Exploratory factor analysis

To examine the underlying factor structure of the 3DSE scale, an exploratory factor analysis (EFA) was conducted. 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 [11, 17]. For this study, the goal is to understand the attributes related to three-dimensional modeling 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 [11].

Before 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 [37]. 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 were suitable for EFA [11]. 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 value of at least .30 [11, 37].

Additionally, sampling adequacy was assessed using the Kaiser-Meyer-Olkin (KMO) correlation. KMO correlation values above .60 were regarded as sufficient to continue with an EFA [11]. 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 [11]. 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 "eye-balling" the correlation matrix, Stata 14 was used to conduct these two tests to determine the appropriateness of the data for EFA.

4.5. Determination of factors

Several considerations were 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 [11, 17, 37]. 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 [37].

A priori knowledge of the instruments, constructs of interest, and the context in which the study was conducted were 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 were retained, is the most common method in determining factor retention [11, 37]. 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 [37]. 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 [37]. These two methods of analysis were the primary method of analysis used in determining the number of factors retained in this study.

4.6. Regression analysis

Correlation analysis was used to determine the existence of the relationship between 3DSE and SEL and student academic outcomes under the assumption that both self-efficacy measures would correlate significantly with the outcome measures but not with each other [5]. 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 [27].

To determine the effect a student's level of 3DSE, 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 [34]. For this study, the participants' mean scores on the 3DSE scale were the predictor (independent) variables used in the analysis with the final course, project, and exam grades as the criterion (dependent) variables.

4.7. Reliability

Reliability (internal consistency) is the degree to which scale items within an instrument are intercorrelated, providing evidence of a commonly related construct [34]. 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 [15]. 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 [33]. Values ranging from 0.70 to 0.95 were considered to be sufficient to consider an instrument reliable [15]. For this study, an alpha of 0.70 was used as a minimum value to determine reliability.

5. Findings

Item level descriptive statistics for the 3DSE scale are displayed in Table 2. Stata 14 was used to analyze the data in this study.

Table 2: Item level statistics for the 3DSE scale

Item	n	M	SD
1	503	5.53	1.04
2	503	5.73	.90
3	503	5.47	1.14
4	503	5.41	1.16
5	503	5.59	1.18
6	503	5.66	1.07
7	503	5.50	1.11
8	503	5.45	1.16
Mean Score	503	5.54	.90

5.1. Exploratory factor analysis

5.1.1. Factorability

Toward investigating the underlying factor structure of the 3DSE scale and addressing the first 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: an examination of the correlation matrix, the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy, and Bartlett's test of sphericity. Table 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 [11].

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 factorability of the sample [11].

Table 3: Correlation matrix for the 3DSE scale

Item	1	2	3	4	5	6	7	8
1	–							
2	.62	–						
3	.61	.76	–					
4	.57	.65	.68	–				
5	.63	.68	.71	.70	–			
6	.58	.72	.71	.60	.69	–		
7	.60	.72	.74	.72	.71	.74	–	
8	.59	.61	.68	.61	.65	.61	.70	–

Note: All correlation coefficients are significant at $p < .05$ *level.*

5.1.2. 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 eight-item scale can be found in Table 4.

Table 4: Factor loadings from exploratory factor analysis: uniqueness, eigenvalues, and percentages of variance for the 3D modeling self-efficacy scale

	Factor Loading			
Item	1	2	3	*Communality*
1	.72	.13	.03	.54
2	.83	-.16	.02	.71
3	.84	-.07	-.06	.71
4	.77	.10	.04	.61
5	.81	.10	.08	.67
6	.80	-.16	.04	.67
7	.85	.13	-.05	.73
8	.73	.11	-.10	.56
Eigenvalue	5.05	.11	.03	
% of Variance	63.14	1.44	.34	

Note: Trace of correlation matrix as the divisor.

Using Kaiser's criterion, factors with eigenvalues greater than 1.00 were retained [37]. To confirm this method, the total variance explained was also examined. Factor one explains 90.41% of the variance in the sample; greater than our determination criteria of .75 [8]. Both methods suggest a single factor structure for the 3DSE scale. The single factor solution is displayed in Table 5.

Table 5: Single factor loading from exploratory factor analysis: communality, eigenvalues, and percentages of variance for the 3D modeling self-efficacy scale

Item	*Factor Loading*	*Communality*
1	.72	.52
2	.83	.68
3	.84	.70
4	.77	.59
5	.81	.65
6	.80	.65
7	.85	.72
8	.73	.54
Eigenvalue	5.05	
% of Variance	63.14	

Note: Trace of correlation matrix as the divisor.

5.1.3. Validity

Toward addressing the second research question—Is there evidence of validity in the domain-specific 3DSE 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 (3DSE and SEL) were regressed on to the dependent variables using Stata 14. A partial correlational analysis was also performed using both predictor and dependent variables (Table 6.).

Table 6: Intercorrelations for predictor variables and student grades

	3DSE	SEL	*Final course grade*	*Final project grade*	*Final exam grade*
3DSE	–				
SEL	.49**	–			
Final course grade	.27**	.13**	–		
Final project grade	.18**	.09**	.70**	–	
Final exam grade	.19**	.06	.61**	.26**	–

*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 3DSE scale and students' final course, project and exam grades. The SEL scale has a statistically significant correlation with students' final course and final project grades; however, no statistically significant correlations were found between the SEL 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 [5] assertion that both self-efficacy measures would correlate significantly with the outcome measures but not with each other.

To address the third research question—What effect does a student's 3DSE 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 7. For student final course grades, the predictor variables explained 6.82% of the total variance, $R^2_{adj} = .0682$, $F(2, 500) = 19.37$, $p < .001$. For student final project grades, the predictor variables explained 2.92% of the total variance, $R^2_{adj} = .0292$, $F(2, 500) = 8.56$, $p < .001$. For student final exam grades, the predictor variables explained 3.43% of the total variance, $R^2_{adj} = .0343$, $F(1, 501) = 18.84$, $p < .001$. It should be noted that simple linear regression—with only the 3DSE score as a predictor variable—as 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 SEL scale, $r = .06$, $p = .160$.

Table 7: Results of the Regression Analysis for the 3DSE and SEL scales

Academic Outcomes		t	p	β	F	df	p	R^2_{adj}
Final course grade	Overall model				19.37	500	<.001	.068
	3DSE	5.43	<.001	1.85				
	SEL	-.010	.994	-.002				
Final project grade	Overall model				8.56	500	<.001	.029
	3DSE	3.59	<.001	1.84				
	SEL	.02	.980	.009				
Final exam grade	Overall model				18.84	501	<.001	.034
	3DSE	4.34	<.001	1.77				

There is significant dependence of 3DSE on 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, every point increase in the 3DSE 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 SEL scale did not display any statistically significant impact when included in the multiple regression model with 3DSE for the students' final course grade, $b = -.002$, $t(500) = -.01$, $p = .994$ or final project grade, $b = .01$, $t(500) = .02$, $p = .980$. The final exam grade was not included in the regression model that included the SEL scale due to its lack of statistically significant correlation between the two variables.

5.1.4. Reliability

The reliability of the 3DSE scale was determined using Cronbach's alpha statistic to address the research question, "Is the domain-specific 3DSE scale reliable?" Based on the stated threshold of .70 [15], the eight-item 3DSE scale is reliable ($\alpha = .94$) with an average inter-item covariance of .83.

6. 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, were positively associated with factors such as persistence and retention in education [26]. In this study, three-dimensional modeling 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 were no domain-specific self-efficacy instruments as required to accurately assess the construct [4]. As such, the psychometric properties of the 3DSE scale were examined 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 3DSE had on major academic outcomes in the course. Toward these goals, 503 students took both the 3DSE and SEL assessments. Their scores on these assessments were then compared to their final course, project, and exam grades. The SEL scale was not the primary measure in this study but used to determine whether evidence of discriminant validity exists.

The 3DSE 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 3DSE 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 3DSE scale reveals that the instrument measures a single construct.

Since self-efficacy and its measurement are domain specific [4] the 3DSE 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 3DSE has a significant contributing role in a student's grades, a student's SEL had little or no impact on academic outcomes. That is not to say that general SEL does not play a role in academic outcomes; in this study, the impact is negligible. It does, however, provide evidence of discriminant validity.

A student's 3DSE 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 [28]. Student sources of self-efficacy and methods by which to create interventions aimed at improving performance, retention, or persistence were beyond the scope of this study. What is of relevance is that the results of the 3DSE scale are consistent with other self-efficacy measures used in other studies and this consistency serves to provide evidence of the validity of the instrument 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 data from the 3DSE demonstrate 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, does not provide enough evidence to support a claim of construct validity even with the described evidences. Construct validity is a high bar and more study is needed in this area.

7. Limitations and future study

Several limitations prevent a decisive conclusion being drawn concerning the psychometric soundness of the 3DSE 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 3DSE instrument and its use with these populations.

The lack of diversity with respect to gender may have to do with the course itself, more specifically, the engineering majors who take it. In this study, on 17% of the students were female versus 42% of the engineering students in the university. This may have to do with the heavy weighting of mechanical engineering students who were predominately male. The proportions of male and female students were similar to those found in engineering graphics courses at other institutions [10]. The ethnic demographics were similar to institutional engineering student demographics.

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.

8. Conclusion

This study examined a Three-Dimensional Modeling Self-Efficacy instrument within an introductory engineering graphics education context. There is evidence of sound psychometric properties with the data used in this study but further investigation with other populations at more diverse universities is needed to paint a more comprehensive picture of the 3DSE. Both deeper and broader investigation into the psychometrics is needed as well as further development of a comprehensive instrument to measure the non-cognitive 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 3D modeling abilities of students in a field that shows both increasing demand and importance as we continue into the 21st-century.

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Received September 12, 2019; final form April 14, 2020