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Online Distribution

The online EDGJ is a reality as a result of support provided by **East Carolina University** and **Biwu Yang**, Research & Development, ECU Academic Outreach.

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Message from the Chair

Norma Veurink, EDGD Chair
Michigan Technological University

The Engineering Design Graphics Division would not exist without the service of its members. Two EDGD members were elected early this year to further their service to the Division. After serving for three years as Director of Communications, Lulu Sun was elected as Vice Chair. Jennifer McInnis was elected as Director of Communications. Jennifer had previously served the division by being the site chair for the 71st Midyear conference this past October. Both of them will assume their positions at the close of the ASEE annual conference. Be sure to thank them both for their continued service to the division.

If you are interested in becoming more involved in EDGD, please talk to one of the division officers or other division member. There are four director positions and a secretary-treasurer position which are for three year terms. Some of these positions need to be filled each year. Each year we also elect a Vice Chair, who becomes the Chair the following year. I served as secretary-treasurer for six years before becoming Vice Chair. Tim Sexton served as secretary-treasurer for nine years before me. Although that may suggest the secretary-treasurer position is more like a life sentence, it really shows that serving on the executive committee is so enjoyable that officers are willing to serve multiple terms. There are also opportunities to help with the *Engineering Design Graphics Journal*, Midyear meetings, and the ASEE annual conference. During my years on the executive board, I have not only been a part of changes in the division over the years, I have also gotten to know and work with other terrific EDGD members. Some of the changes I have been a part of as a board member over the years are an increased focus on attracting new members to the division, coffee and donut sessions at the annual conference, changes to the format of Midyear proceedings to increase opportunities for publication, and two international Midyear meetings (Limerick, Ireland, Nov 2012, and Jamaica, Jan 2018). I encourage each of you, but especially the "newer" members of the division, to be a catalyst for EDGD growth and innovation.

Hope you enjoy this Winter issue of the *Engineering Design Graphics Journal*.

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Message from the Editor

AJ Hamlin, EDGJ Editor
Michigan Technological University

Both articles in this issue pertain to spatial visualization, a topic that is near and dear to me. My first exposure to the importance of spatial visualization skills for engineering students was in my first semester of teaching at Michigan Tech. I was teaching ENG1102 — Engineering Modeling and Design, which includes solid modeling and engineering graphics. When creating isometric sketches and orthographic projections of objects with oblique surfaces, I noticed several students that were moving easily through the assignments and helping their neighbors. In talking with those students, I learned they had taken Sheryl Sorby's, Introduction to Spatial Visualization course the previous semester. Since then, I have had the pleasure of teaching the spatial visualization course. I have seen numerous students improve their spatial visualization skills and the confidence that instills in them in ENG1102.

In "Factors of Spatial Visualization: An Analysis of the PSVT:R," the authors examine a common instrument used to assess spatial skills to gain a better understanding of what factors the instrument measures.

In "Use of Virtual Reality Head-Mounted Displays for Engineering Technology Students and Implications on Spatial Visualization," the authors explore exposing students to different representations of an object (3D solid model, 3D printed part, and Oculus Virtual Reality head-mounted display) to see if there is a difference in their ability to sketch the rotational views of the object.

I hope you enjoy this issue!

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EDGD Calendar of Events

Future ASEE Engineering Design Graphics Division Mid-Year Conferences

72nd Midyear Conference – January 2018, Jamaica
Site Chair – Sheryl Sorby and Norman Loney.
Program Chair – Mary Sadowski.
Conference site: edgd.asee.org/72

Future ASEE Annual Conferences

Year	Dates	Location	Program Chair
2017	June 25 - 28	Columbus, Ohio	Theodore Branoff
2018	June 24 - 27	Salt Lake City, Utah	Heidi Steinhauer
2019	June 16 - 19	Tampa, Florida	
2020	June 21 - 24	Montréal, Québec, Canada	
2021	June 27 - 30	Long Beach, California	
2022	June 26 - 29	Minneapolis, Minnesota	
2023	June 25 - 28	Baltimore, Maryland	

If you're interested in serving as the Division's program chair for any of the future ASEE annual conferences, please make your interest known.

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Election Results

According to the Division by-laws (available at: http://edgd.asee.org/aboutus/index.htm), the chair of the Elections Committee shall transmit the results of the election to the Chair of the Division. The Chair shall inform each candidate (including those not elected) of the results of the election for his office and shall transmit the names of the newly-elected officers to the Editor of the *Journal* for publication in the Spring issue of the *Journal*. The chair of the Elections Committee shall report the results of the election to the Division at the annual business meeting. The results for the most recent election are as follows:

Vice-Chair: Lulu Sun

Lulu Sun is an associate professor in the Engineering Fundamentals Department at Embry-Riddle Aeronautical University, where she has taught since 2006. She received her Ph.D. degree in Mechanical Engineering from University of California, Riverside, in 2006, and B.S. degree in Mechanical Engineering from Harbin Engineering University (China), in 1999. Before joining Embry-Riddle, she worked in the consulting firm of Arup at Los Angeles office as a fire engineer. She is a professional member of the Society of Fire Protection Engineer, and a member of American Society of Engineering Education. Her research interests include the incorporation of active learning techniques as well as integration of innovation and entrepreneurship into the engineering graphics course. In addition, she is active in creating E-learning environments to enhance the learning experience of students. She is the winner of 2013 Chair's Award and the 2014 Media Showcase Award.

Director of Communications: Jennifer McInnis

Jennifer McInnis is currently an assistant professor of Mechanical Engineering at Daniel Webster College in New Hampshire, and will be transitioning with the DWC engineering program to Southern New Hampshire University in the fall. She earned her B.S. degree in Aeronautical Engineering from Daniel Webster College in 2008, her M.S. degree in Mechanical Engineering from Worcester Polytechnic Institute in 2012, and is in the final stages of earning her Ph.D. in Mechanical Engineering from WPI. She began teaching at DWC in 2014, teaching freshman design courses and sophomore engineering sciences. She has worked in manufacturing engineering at UltraSource Inc., focusing on continuous improvement, process documentation, and quality initiatives, and has also researched with a small medical technology company, D'Ambra Technologies. She is a member of the Society of Women Engineers and American Society of Engineering Education and received the 2009 Chair's Award.conventional tolerancing and geometric dimensioning and tolerancing and authored a textbook on interpreting engineering drawings.

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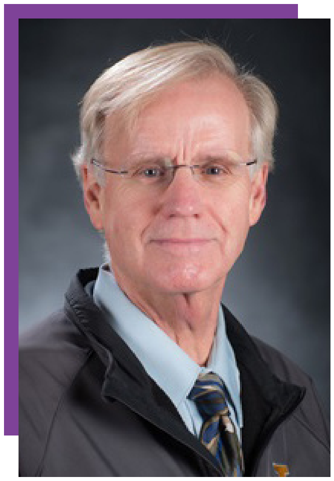
The Chair's Award



Edwin Odom

Steven Beyerlein

The 2016 Chair's Award goes to **Edwin Odom** and **Steven Beyerlein** of the University of Idaho, Moscow for their paper, "Using Solid Modeling to Enhance Learning in Mechanics of Materials and Machine Component Design." Their paper can be downloaded from https://peer.asee.org/using-solid-modeling-to-enhance-learning-in-mechanics-of-materials-and-machine-component-design. The Chair's Award recognizes the outstanding paper presented at an EDGD sponsored ASEE Annual Conference session and carries a cash award.

The award description can be found at:

http://edgd.asee.org/awards/chairs/index.htm

The past awardees list can be found at:

http://edgd.asee.org/awards/chairs/awardees.htm

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Factors of Spatial Visualization: An Analysis of the PSVT:R

Jeremy V. Ernst and Thomas O. Willams
Virginia Tech

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North Carolina State University

Abstract

The Purdue Spatial Visualization Test: Visualization of Rotations (PVST:R) is among the most commonly used measurement instruments to assess spatial ability among engineering students. Previous analysis that explores the factor structure of the PSVT:R indicates a single-factor measure of the instrument. With this as a basis, this research seeks to examine the psychometric properties of the test. This paper presents the findings of single and multi-factor analyses of the PSVT:R given to 335 students enrolled in an introductory engineering design graphics course. Initial analysis did not support a single factor solution. Further examination of pattern analyses and communalties are suggestive of the possibility that the PSVT:R may load on multiple factors. The magnitude of the variance is not explained by a single factor and whether the PSVT:R can be considered a single construct measure of mental rotation ability is not supported by this study. This represents a potential divergence from the current literature and may call into question the replicability of the test's psychometric properties.

Introduction

Calls for greater numbers of practitioners with skills in the fields of science, technology, engineering, and mathematics (STEM) are only increasing as global and societal demands for innovation in technology, medicine, transportation, communications, and other markets continue to advance (Kuenzi, 2008). Spatial visualization skills represent a key component in a variety of STEM fields and of crucial importance in technical professions such as engineering (Sorby, 1999; Torpey, 2013). STEM credentialed professionals tend to demonstrate notable levels of spatial ability as students with skills significantly greater than those of their peers (Lubinski, 2010).

Spatial ability assessments have been shown to have strong correlations with, and be a possible predictor of, success in engineering graphics courses (Maeda, Yoon, Kim-Kang, & Imbrie, 2013; Sorby, 1999). Several measurement instruments frequently used in engineering education include the Mental Rotations Test (MRT), the Mental Cutting Test (MCT), the Revised Minnesota Paper Form Board Test (RMPFBT), the Differential Aptitude Tests: Spatial Relations (DAT:SR), and the Purdue Spatial Visualization Tests: Visualization of Rotations (PVST:R) (Maeda et al., 2013).

Along with holding significance as a factor in STEM education, spatial ability has also been shown to have some levels of malleability with respect to instruction with some training having an overall effect size of 0.47 standard deviations (Uttal, Miller, & Newcombe, 2013). Sorby (2009) demonstrated that spatial skills, as measured with a stan-

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dard instrument, can be improved with training in an undergraduate engineering class environment. Current literature contends that increased spatial thinking or reasoning abilities provide potential predictive value for success in academic and career pursuits (Uttal et al., 2013) as well as being a demonstrable need as a focus in STEM learning environments.

As there is a growing shift from two-dimensional and three-dimensional modeling in engineering graphics courses (Clark, Scales, & Petlick, 2005) along with greater inclusion of solid modeling programs in high school curricula, the psychometric properties of the instruments used to assess and evaluate spatial visualization skills among students is of increasing importance. With the move to more STEM integration in secondary schools, it can be presumed that the need to more accurately assess the skills of students will grow with it. This study offers insight into the psychometric properties of the PSVT:R in order to determine what factors the instrument assesses so that modifications to engineering graphics curricula and pedagogies can be properly assessed with respect to student spatial visualization skills.

Instrumentation

The PSVT:R is among the most popular and common tests within engineering education to measure students' spatial visualization, specifically mental rotation, abilities (Field, 2007). Initially developed by Guay (1976), the PSVT:R was an extended subsection of the Purdue Spatial Visualization Tests (PSVT). The original PVST included three subtests of 12 items each titled Developments, Rotations, and Views. Each subtest also had 30-item extended independent versions: the Visualization of Views (PSVT:V), Visualizations of Rotations (PVST:R) and Visualization of Developments (PSVT:D) (Maeda et al., 2013).

Along with its popularity as an assessment tool in engineering education, the PSVT:R (along with the MCT) also appears to have high construct validity when measuring spatial visualization ability (Branoff, 1998). The PVST:R is also unique due to its use of inclined, oblique, and curved surfaces as they are more demanding to visualize than simple cubically-shaped objects (Yue, 2004).

Part of the impetus for the development of the PVST:R was that other tests may be vulnerable to analytic or non-spatial strategies for the solving of items (Yoon, 2011). Participants may be able to employ strategies other than mental manipulation of objects to solve items, thereby negating a test's capacity to genuinely measure spatial abilities. The PSVT:R was revised by Yoon (2011) in part to address figural errors such as missing lines as well as changes to the format of the instrument to address possible measurement errors and limit the possibility for participant distraction by limiting the number of items per page to one (Maeda et al., 2013).

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Whether the original or Revised PVST:R, little empirical research exists into the psychometric properties of the test. While Maeda et al. (2013) describes the Revised PSVT:R as “a psychometrically sound instrument” (p. 763) with respect to first-year engineering students, limited evidence to that claim involves the study described in that paper and the doctoral dissertation of Yoon (2011) in which the Revised PVST:R was developed. However, Yoon (2011) and Maeda and Yoon (2011, 2013) cite a lack of empirical study investigating the psychometric properties of the PVST:R.

The apparent dichotomy that exists in the literature as to the psychometric trustworthiness of the PSVT:R requires further investigation in order to examine what factors, if any, the instrument measures. As the PSVT:R, whether in its original or revised form, remains an accepted and common assessment of students spatial visualization skills The lack of empirical study and/or factor analysis is concerning to the authors.

While some studies focus on engineering students as a general population (Field, 2007; Maeda et al., 2013; Sorby, 2009; Sorby & Baartmans, 2000), few published studies focus specifically on engineering graphics courses (Branoff, 1998). Some recent research utilizing the PSVT:R in engineering graphics courses (Branoff, Brown, & Devine, 2015; Rodriguez & Rodriguez, 2015) establish the contemporary use of the test. This extant research presents a timely justification for an examination into the psychometric properties of the PSVT:R.

Methods

Participants in this study were given the PSVT:R during the 11th week of an introductory engineering graphics course in a major university undergraduate program. Participants were largely declared STEM majors with 75% of the total sample group being engineering students. Freshmen were represented three to one when compared to other class levels. Males comprised 78.5% of the sample population (Table 1).

Table 1
Demographic Information for Study Participants

Participant Major (percentages)

Engineering	Science & Math	Technology	Education	Other Declared	Undeclared
75	4.2	6.3	2.1	8.5	3.9

Participant Class Level (percentages)

Freshman	Sophomore	Junior	Senior	Other
75	4.2	6.3	2.1	8.5

Participant Gender (percentages)

Male	Female
78.5	20.9

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The course used in this research represents a diverse range of majors from throughout the university. The 11th week was selected because it is the point in the course where most of the content and practice work was completed and prior to the students starting their final projects. Over the course of two years, in both the fall and spring semesters, 335 tests were completed. The PSVT:R figures were displayed on the individual participant's computer screens and the answers were recorded on paper by the participating students. Participants were able to move back and forth though the figures as needed. The collected answer sheets were then entered into a database for analysis.

A critical methodological decision for researchers using factor analysis is determining the number of factors to retain. In this study, the number of factors to retain was examined through multiple methods as there is no singular exacting process (Gorsuch 2003). Because the PSVT was designed to measure one factor, an *a priori* one-factor solution was examined. The scree test (Cattell, 1966; Cattell & Jaspers, 1967) and parallel analyses (Lorenzo-Seva & Ferrando, 2006) were also employed to determine factor retention. Data were analyzed using Factor 9.3 (Lorenzo-Seva & Ferrando, 2006). Raw scores for the PSVT were submitted to unweighted least squares factor analysis with the oblique promax rotation. The promax rotation was selected because any factors resulting from the analysis were hypothesized to be correlated. The polychoric correlation matrix Factor 9.3 generated for the analyses is shown in Table 2. Based on the number of participants, pattern coefficients of .30 or greater were considered to be salient (Gorsuch, 1983; Hair, Anderson, Tatham, & Black, 1998).

Results

The results of the scree test (Figure 1) appeared to support a three-factor solution. A parallel analysis analyses by comparing the sample data and those for 1000 sets of randomly generated data (Lorenzo-Seva & Ferrando, 2006; Timmerman & Lorenzo-Seva, 2011), the percent of variance for the randomly generated data exceeded the variance for the sample data after the second factor when using the 95th percentile, suggesting a two-factor solution. Therefore, one-, two-, and three-factor solutions were examined.

The Kaiser-Meyer-Olkin index of sampling adequacy was .81, indicating that the data represented a homogeneous collection of variables that were suitable for factor analysis. Bartlett's test of Sphericity was significant for the sample [x2 (435, N = 335) = 1862.50; $p < .001$], indicating that the set of correlations in the correlation matrix was significantly different from zero and suitable for factor analysis.

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Table 2
Correlation Matrix for Test Items

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
V 1	1.00																													
V 2	**0.90**	1.00																												
V 3	**0.46**	**0.56**	1.00																											
V 4	**0.31**	0.13	0.26	1.00																										
V 5	0.05	0.00	0.22	0.12	1.00																									
V 6	0.00	0.00	0.00	0.19	**0.38**	1.00																								
V 7	0.20	0.16	0.14	0.00	0.00	0.25	1.00																							
V 8	0.00	0.03	0.00	0.00	0.00	0.00	0.00	1.00																						
V 9	0.00	0.00	0.00	0.06	0.00	0.19	0.00	0.05	1.00																					
V 10	0.30	**0.33**	0.17	0.08	0.00	0.22	0.41	0.23	0.30	1.00																				
V 11	0.21	0.25	0.02	0.00	0.00	0.15	0.33	0.23	0.19	0.28	1.00																			
V 12	0.15	0.24	0.00	0.00	0.00	0.00	0.17	0.00	0.08	0.21	**0.31**	1.00																		
V 13	0.04	0.12	0.00	0.06	0.00	0.08	0.19	0.00	0.00	0.26	0.00	0.00	1.00																	
V 14	0.23	0.19	0.05	0.00	0.17	0.11	0.00	0.07	0.22	**0.31**	0.11	**0.35**	0.00	1.00																
V 15	0.02	0.05	0.00	0.00	0.25	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	1.00															
V 16	0.00	0.00	0.04	0.18	0.02	0.00	0.00	0.00	0.08	0.18	0.00	0.11	0.04	0.00	**0.37**	1.00														
V 17	0.18	0.12	0.00	0.11	0.24	0.20	0.00	0.00	0.11	0.30	0.00	0.08	0.00	0.18	0.28	0.15	1.00													
V 18	0.17	0.29	0.00	0.15	0.00	0.17	0.21	0.05	0.15	0.29	0.10	0.15	0.10	0.26	0.04	0.07	0.18	1.00												
V 19	0.05	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.08	0.08	0.00	0.00	0.06	0.02	0.00	0.01	0.00	1.00											
V 20	0.00	0.03	0.00	0.11	0.07	0.13	0.24	0.06	0.02	0.18	0.13	0.09	0.00	0.17	0.00	0.06	0.00	0.11	0.18	1.00										
V 21	0.00	0.00	0.00	0.00	0.00	0.09	0.06	0.00	0.00	**0.31**	0.15	0.14	0.00	0.18	0.00	0.04	0.00	0.15	0.10	**0.37**	1.00									
V 22	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.03	0.00	0.06	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.03	0.00	0.04	0.15	1.00								
V 23	0.02	0.04	0.00	0.00	0.00	0.00	0.11	0.00	0.03	0.14	0.05	0.27	0.03	0.03	0.00	0.16	0.00	0.08	0.03	0.00	0.15	0.00	1.00							
V 24	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.05	0.10	0.11	0.00	0.00	0.06	0.00	0.00	0.04	0.00	0.00	0.11	0.07	0.12	1.00						
V 25	0.00	0.00	0.00	0.00	0.00	0.10	0.14	0.00	0.08	0.19	0.00	0.18	0.08	0.13	0.03	0.03	0.00	0.00	0.07	0.09	0.13	0.00	0.18	0.25	1.00					
V 26	0.00	0.00	0.00	0.03	0.00	0.12	0.08	0.00	0.30	0.12	0.03	0.09	0.00	0.02	0.00	0.14	0.00	0.05	0.01	0.27	0.02	0.11	0.26	0.21	0.24	1.00				
V 27	0.00	0.14	0.00	0.00	0.00	0.06	0.07	0.00	0.01	0.15	0.10	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.07	0.00	0.00	0.06	0.07	0.10	0.05	1.00			
V 28	0.03	0.04	0.00	0.00	0.00	0.11	0.04	0.00	**0.33**	0.25	0.11	0.07	0.01	0.25	0.00	0.03	0.00	0.00	0.06	0.11	0.21	0.03	0.28	0.00	0.21	0.41	0.00	1.00		
V 29	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.01	0.00	0.08	0.13	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.01	0.11	0.17	0.21	1.00	
V 30	0.12	0.04	0.00	0.05	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.06	0.00	0.15	0.00	0.14	0.00	0.03	0.00	0.09	0.00	0.00	0.00	0.13	0.24	0.25	0.01	0.11	0.00	1.00

Note. Significant correlations (>.30) are in bold.

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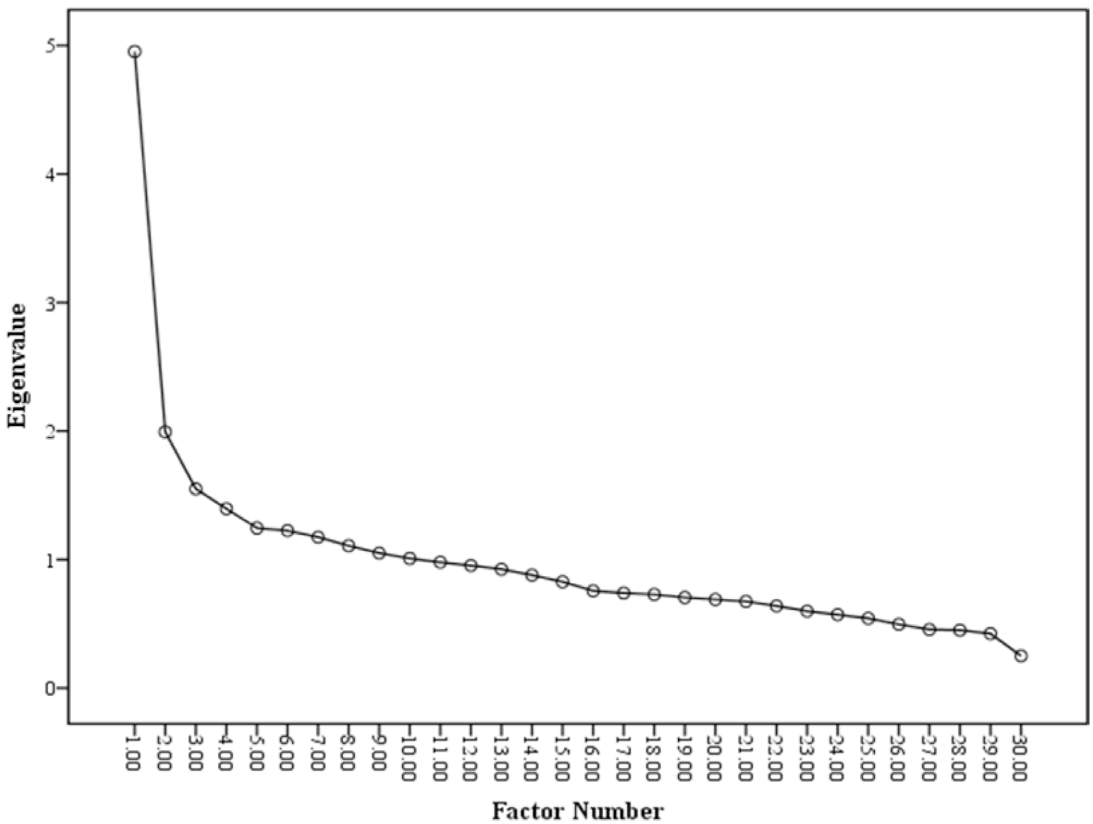

Figure 1. Results of the scree test with eigenvalues

Table 3 shows the loadings for one-, two-, and three-factor solutions. In the one-factor solution, approximately 12 percent of the variance was explained and only 10 of the test items loaded on the factor. The reliability of the 10 item scores that loaded on one factor was .80.

The loadings for the two-factor rotated solution (shown in Table 3) reveal approximately 20 percent of the variance was explained with the first factor accounting for 12 percent and the second factor accounting for eight percent. Eight items loaded on factor one and three items loaded on factor two. The interfactor correlation was .24.The reliability of the eight items for factor one was .76 and .94 for the three items on factor two.

Table 3 also shows the loadings for the three-factor rotated solution. In the three-factor rotated solution, approximately 26 percent of the variance was explained with the first factor accounting for 12 percent and the second factor accounting for eight percent and the third factor accounting for six percent. Two items loaded on factor one and four items loaded on factor two, and 10 items loaded on factor three. The interfactor correlation for factor one and factor two was .21; factor one and factor three was .25; and factor two and factor three was .32. The reliability of the two items for factor one was .99, the four items for factor two was .64, and .75 for the 10 items on factor three.

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Table 3
Pattern Coefficients and Communalities (h2) for One-, Two-, and Three-Factor Solutions

	One-Factor	h^2	Two-Factor Rotated		h^2	Three-Factor Rotated			h^2
	1		1	2		1	2	3	
V1	**0.54**	0.292	-0.081	**0.91**	0.8	0.094	-0.008	-0.07	0.788
V2	**0.578**	0.334	-0.064	**0.967**	0.909	**1.022**	-0.118	-0.018	1
V3	**0.308**	0.095	-0.107	**0.543**	0.287	**0.528**	0.067	-0.132	0.275
V4	0.223	0.05	0.033	0.252	0.069	0.208	0.239	-0.066	0.109
V5	0.143	0.02	0.082	0.089	0.018	-0.012	**0.567**	-0.15	0.288
V6	0.288	0.083	**0.318**	0.021	0.105	-0.076	**0.0484**	0.14	0.282
V7	**0.4**	0.16	0.299	0.186	0.151	0.179	0.02	0.297	0.152
V8	0.119	0.014	0.105	0.035	0.014	0.033	0.008	0.102	0.014
V9	0.286	0.082	0.289	-0.043	0.145	-0.066	0.116	**0.344**	0.147
V10	**0.706**	0.499	0.563	0.293	0.482	0.26	0.161	**0.5**	0.477
V11	**0.396**	0.157	0.293	0.192	0.15	0.2	-0.043	**0.317**	0.162
V12	**0.395**	0.156	**0.343**	0.141	0.161	0.157	-0.084	**0.387**	0.186
V13	0.163	0.027	0.109	0.089	0.025	0.081	0.039	0.094	0.024
V14	**0.425**	0.181	**0.355**	0.165	0.182	0.137	0.144	0.299	0.184
V15	0.098	0.01	0.076	0.04	0.009	-0.037	**0.423**	-0.1	0.159
V16	0.172	0.029	0.196	0.008	0.039	-0.037	0.235	0.099	0.076
V17	0.262	0.069	0.151	0.167	0.063	0.081	**0.512**	-0.056	0.269
V18	**0.384**	0.148	0.249	0.22	0.137	0.189	0.169	0.181	0.147
V19	0.138	0.019	0.125	0.047	0.021	0.054	-0.03	0.138	0.023
V20	0.283	0.08	**0.371**	-0.03	0.133	-0.041	0.056	**0.35**	0.132
V21	0.281	0.079	**0.384**	-0.047	0.141	-0.047	0.001	**0.387**	0.143
V22	0.058	0.003	0.093	-0.024	0.008	-0.033	0.048	0.073	0.009
V23	0.226	0.051	**0.334**	-0.057	0.106	-0.039	-0.107	**0.387**	0.131
V24	0.127	0.016	0.209	-0.056	0.041	-0.042	-0.077	0.245	0.052
V25	0.248	0.062	**0.395**	-0.092	0.147	-0.079	-0.076	**0.435**	0.116
V26	0.264	0.069	**0.488**	-0.157	0.226	-0.148	-0.057	**0.522**	0.243
V27	0.15	0.022	0.141	0.042	0.025	0.054	-0.059	0.169	0.032
V28	**0.317**	0.101	0.511	-0.111	0.246	-0.102	-0.06	**0.546**	0.266
V29	0.077	0.006	0.131	-0.039	0.016	-0.037	-0.01	0.138	0.017
V30	0.153	0.024	0.19	0.001	0.036	0.009	-0.045	0.212	0.042
Note. Salient pattern coefficients are in bold type.									

Conclusion

Prior analysis of the PSVT:R describes the test as loading on a single factor, which indicates a single construct measure of mental rotation ability (Maeda et al., 2013). This study, in part, was designed to test this premise in an introductory engineering graphics course under a null hypothesis of the PSVT:R representing a single construct measure. In this study, analysis on a single factor did not explain the magnitude of variance anticipated. This led to further examination using rotated factors for a two-factor solution as well as a three-factor solution. The result of the three-factor analysis of the 335 first-year graphics communications students, shows the PSVT:R loading on multiple factors. This suggests that mental rotation abilities of introductory engineering design graphics students, as measured by the PSVT:R, is inconsistent with the prior Maeda et al. (2013) study. It is acknowledged that the current study was conducted with dissimilar test populations from previous studies exploring factor composition. There is evidence that the PSVT:R was a significant predictor of student success in first year graphics courses (Sorby & Baartmans, 2000). However, our analysis demonstrates multiple unknown measured factors. This analysis raises questions as to what the test measures concerning specific constructs. More investigation is needed to determine what factors the PSVT:R consistently measure and its use as a single construct predictor.

References

Branoff, T. J., Brown, J. W., & Devine, K. L. (2016). 3D spatial visualization instruction within an introductory constraint-based cad modeling course. Published proceedings of the *Engineering Design Graphics Division of the American Society of Engineering Education's 70th Midyear Conference,* Daytona Beach, FL, 65-72.

Branoff, T. J. (1998). The Effects of Adding Coordinate Axes to a Mental Rotations Task in Measuring Spatial Visualization Ability in Introductory Undergraduate Technical Graphics Courses. *Engineering Design Graphics Journal, 62*(2), 16-34.

Cattell, R. B. (1966). The scree test for the number of factors. *Multivariate Behavioral Research*, *1*, 245-276.

Cattell, R. B., & Jaspers, J. (1967). A general plasmode for factor analytic exercises and research. *Multivariate Behavioral Research Monographs*, *3*, 1-212.

Clark, A. C., Scales, A. Y, & Petlick, J. (June, 2005). Trends and Issues for Engineering/Technical Graphics Education: A Follow-up Survey. Published Refereed Proceedings for the American Society for Engineering Education Annual Conference, Portland, OR.

Field, B. W. (2007). Visualization, intuition, and mathematics metrics as predictors of undergraduate engineering design performance. *Journal of Mechanical Design, 129*(7), 735-743. doi:10.1115/1.2722790

Gorsuch, R. L. (1983). *Factor analysis* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum.

Gorsuch, R. L. (2003). Factor analysis. In I. B. Weiner, J. A. Schinka, & W. F. Velicer (Eds.), Handbook of psychology: Vol. 2. *Research methods in psychology* (pp. 143–164). Hoboken, NJ: Wiley.

Guay, R. (1976). *Purdue Spatial Visualization Test*. West Lafayette, IN: Purdue Research Foundation.

Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1998). *Multivariate data analysis.* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

Hinkle, D. E., Wiersma, W., & Jurs, H. W. (1988). *Applied Statistics for the Behavioral Sciences*. Boston, MA: Houghton Mifflin Company.

Kuenzi, J. J. (2008). *Science, technology, engineering, and mathematics (STEM) education: Background, federal policy, and legislative action.* Congressional Research Service: University of Nebraska - Lincoln.

ISSN: 1949-9167

Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1998). *Multivariate data analysis.* (5th ed.). Upper Saddle River, NJ: Prentice Hall.

Lubinski, D. (2010). Spatial ability and STEM: A sleeping giant for talent identification and development. *Personality and Individual Differences, 49*(4), 344-351.

Maeda, Y., & Yoon, S. Y. (2011). *Scaling the Revised PSVT-R: Characteristics of the first year engineering students' spatial ability.* Paper presented at the 118th ASEE Annual Conference & Exposition, Vancouver, BC, Canada.

Maeda, Y., & Yoon, S. Y. (2013). A meta-analysis on gender differences in mental rotation ability measured by the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R). *Educational Psychology Review, 25*(1), 69-94. doi:10.1007/s10648-012-9215-x

Maeda, Y., Yoon, S. Y., Kim-Kang, G., & Imbrie, P. (2013). Psychometric properties of the Revised PSVT:R for measuring first year engineering students' spatial ability. *International Journal of Engineering Education, 29*(3), 763-776.

Rodriguez, J., & Rodriguez, L.G. (2016). Comparison of spatial visualization skills in courses with either graphics or solid modeling content. Published proceedings of the *Engineering Design Graphics Division of the American Society of Engineering Education's 70th Midyear Conference,* Daytona Beach, FL, 51-56.

Sorby, S. A. (1999). Developing 3-D spatial visualization skills. *Engineering Design Graphics Journal, 63*(2), 21-32.

Sorby, S. A. (2009). Educational research in developing 3-D spatial skills for engineering students. *International Journal of Science Education, 31*(3), 459-480. doi:10.1080/09500690802595839

Sorby, S. A., & Baartmans, B. J. (2000). The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students. *Journal of Engineering Education, 89*(3), 301-307.

Timmerman, M. E., & Lorenzo-Seva, U. (2011). Dimensionality Assessment of Ordered Polytomous Items with Parallel Analysis. *Psychological Methods, 16*, 209-220.

Torpey, E. M. (2013). College to career: projected job openings in occupations that typically require a bachelor's degree.

Uttal, D. H., Miller, D. I., & Newcombe, N. S. (2013). Exploring and enhancing spatial thinking links to achievement in science, technology, engineering, and mathematics? *Current Directions in Psychological Science, 22*(5), 367-373.

Yoon, S. Y. (2011). Psychometric Properties of the Revised Purdue Spatial Visualization Tests: Visualization of Rotations (The Revised PSVT-R). *ProQuest LLC*.

Yue, J. (2004). Spatial visualization by orthogonal rotations. *Proceedings of the American Society for Engineering Education (ASEE) Annual Conference and Expositions*, Salt Lake City, Utah.

Note

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Use of Virtual Reality Head-Mounted Displays for Engineering Technology Students and Implications on Spatial Visualization

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Abstract

Results from a number of studies indicate that the use of head-mounted displays can influence spatial visualization ability; however, research provides inconsistent results. Considering this, a quasi-experimental study was conducted to identify the existence of statistically significant effects on rotational view drawing ability due to the impacts of the displays. In particular, the study compared the use of three different types of displays; head-mounted, pc dynamic and 3D printed and whether a significant difference exists towards rotational view drawing ability, among engineering technology students. According to the results of this study it is suggested that the impact of the display type provides no statistically significant differences.

Introduction

Virtual reality (VR) technology dates back to the 1960s and is defined as the "computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors" (Oxford Dictionaries, 2015). Since the 1960s, VR use has evolved in business and industry, as well as in the classroom. Burdea (2004) is one of the first authors who acknowledged issues with teaching virtual reality. He expressed concern for the lack of faculty experts, textbooks, dedicated laboratories, and curriculum content on VR. Through an informal survey, Burdea (2008) found that only 148 universities offered VR studies, however, by 2008 this number increased to 273 universities.

Review of Literature

Spatial Ability

The term spatial ability varies in definition, to include a range of abilities across the years and by different authors. Researchers, for the most part, recognize five elements in particular: spatial perception, spatial visualization, mental rotations, spatial relations, and spatial orientation (Maier, 1994). Spatial skills are a component of aptitude critical to success in engineering, technical, and scientific fields (Martín Gutiérrez, García Domínguez, & González, 2015). In addition, spatial ability has been widely researched in the areas of science, technology, engineering, and mathematics (STEM). Related research determined that retention and student success in engineering education depends largely on highly developed spatial skills. In addition, research has also shown that different instructional methodologies may increase student spatial ability achievement in different disciplines, including engineering and science education (Häfner, Häfner, & Ovtcharova, 2013; Martín-Gutiérrez et al., 2015; Rafi, Anuar-Samsudin, & So-Said, 2008).

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Spatial Ability and Virtual Reality

Virtual reality is recognized as a “set of technologies and interfaces which allow one or more users to interact in real time with a computer-generated 3D environment or dynamic world” (Martín Gutiérrez et al., 2015, p. 325). In Rafi, Anuar, Samad, Hayati, and Mahadzir (2005) study of pre-service teachers using virtual reality for spatial ability learning, subjects showed improvement in their mental rotation abilities, as well as a marginal gain in spatial visualization. Traditionally, engineering courses have sought to achieve a near equal amount of mathematical precision and practical applications in a laboratory environment (Tibola, Pereira & Tarouco, 2014).

Lee and Wong (2014) found a significant difference in achievement for those students in a VR-based learning environment than the control group who used PowerPoint slides. In particular, it was determined that low spatial ability learners showed significant gains in spatial ability. Martín Gutiérrez et al. (2015) found that the use of 3D virtual technologies significantly improved spatial skills of the subjects studied. In addition, the results revealed that more than half of the students exposed to the traditional methods (non-3D environments) were not able to pass an Engineering Graphic Design course, while those exposed to the 3D methods showed a 60% pass rate.

Visualization and Virtual Reality

Visualization, a component of spatial abilities, is defined as the “ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object” (McGee, 1979). It is important to note here that research reveals many definitions, but they all reinforce the basic characterization of mentally rotating an object in the mind’s eye or “mental management” of complex shapes (Martín Gutiérrez et al., 2015). Sorby and Baartmans’s (1996) study on a newly implemented semester course that integrated virtual geometric objects, which could be sliced and rotated, revealed successful learning outcomes in spatial visualization. Sorby and Baartmans (2000) found that year after year, students completing this course showed statistically higher graphics grades, as well as an increase in engineering retention.

Chen (2006) found that learners with high and low spatial visualization ability benefited from guided VR treatment (a learning mode that uses a VR-based learning environment with additional navigational aids) and outperformed those with non-guided VR and non-VR treatments. The interactive effect between spatial visualization ability and the learning mode revealed no significance differences. This result further supports the finding that learners benefit from guided VR treatment regardless of spatial visualization ability.

Virtual Reality head-mounted display (Oculus™)

While virtual reality is not new to educational environments, Oculus™ is just beginning

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to break barriers, especially in engineering and science education. Due largely to high cost and lack of expertise, Oculus™ technology has been in the background until its recent release into gaming and other popular technologies on the market. Sony and Microsoft have entered the market by developing Xbox live and Sony PlayStation to bring virtual worlds to the home and marketplace (Callaghan, McCusker, Lopez-Losada, Harkin, & Wilson, 2009). The Oculus™ Rift should be released later this year, and Sony plans a project launch date in 2016 for their virtual reality head-mounted display, Project Morpheus. Retail versions of Oculus™ will offer resolutions higher than the typical 1,920 by 1,080 pixels per eye. This technology will soon become a household standard that was unimaginable 30 years ago when similar technology started at $100,000 (Parkin, 2014).

Head-Mounted Displays (HMDs) like Oculus™ allow users to experience full immersion, permitting a realistic 3D setting similar to a physical environment (Beattie, Horan & McKenzie, 2015). Oculus™ technology has only been on the market a short time. It is the most commonly used in education, specifically in computer science, followed by engineering and mathematics (Freina & Ott, 2015). The most relevant research related to this technology has been conducted and published in the United States, followed by Germany. In addition, most of the research on VR and HMDs has been related to higher education or adult training, since immersive VR may hinder the cognitive and physical development of children. VR and HMDs support learner engagement and motivation, as well as a range of learning styles (Freina & Ott, 2015).

Virtual Reality in Engineering Education

With recent evolutions of computer hardware and software, lower associated costs, and an increase in expertise in the field, Virtual Reality has become a more feasible teaching solution in Engineering education, as well as other educational environments and disciplines (Abulrub, Attridge, & Williams, 2011; Häfner, et al., 2013). There is a new generation of computer savvy engineering students entering higher education with the expectation of learning cutting-edge technologies. This requires faculty to understand the needs of these students and to provide programs that offer advanced learning environments with 3D visualization technologies and state-of-the-art curriculums. Virtual environments not only promote learning, they also promote innovation and creativity, which allows students to be engaged and successful in their educational environments. Abulrub et al.'s (2011) study found that using 3D interactive virtual reality visualization systems to prepare engineering students for an authentic experience in industry considerably improves the efficiency of both teaching and training. Furthermore, students are able to apply theoretical knowledge domains to complex real-world problems in an educational environment that has active learning components and enhances student motivation.

Virtual Reality and 3D Modeling

Advanced engineering courses depend on the students' ability to visualize three-dimen-

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sional (3D) objects as interconnected parts and as a whole. The dynamic nature of such objects is equally important (Flanders & Kavanagh, 2013). A study by Cohen and Hegarty (2014) reveals interventions using virtual models and interactive animations are effective in training children on simple spatial skills, as well as more complex spatial skills in adults. Yurt and Sünbül's (2012) study showed significantly higher scores for mental rotation in those students assigned to a virtual environment.

Combining VR and 3D graphics provides an environment that can enhance a user's spatial ability. Research suggests the 3D immersive virtual environment is more efficient in training spatial ability and skills than the 2D or 3D non-immersive environments. The evolution of computer software and the decrease in costs has introduced an environment supportive of virtual reality and 3D modeling (Fillatreau et al., 2013).

Research Question and Hypothesis

To enhance the body of knowledge related to VR in the college classroom, the following study was conducted.

The following was the primary research question:

> Does the mode of displaying a rotating 3D geometric shape (PC image, 3D physical model, PC image viewed through a head-mounted display) have an effect on students': a) Spatial visualization ability as measured by the MRT and b) ability to sketch a rotational view drawing?

The following hypotheses will be analyzed in an attempt to find a solution to the research question:

> H_0: There is no effect on students': a) Spatial visualization ability as measured by the MRT and b) ability to sketch a rotational view drawing due to the mode of displaying a rotating 3D geometric shape (PC image, 3D physical model, PC image viewed through a head-mounted display).

> H_A: There is an identifiable amount of effect on students': a) Spatial visualization ability as measured by the MRT and b) ability to sketch a rotational view drawing due to the mode of displaying a rotating 3D geometric shape (PC image, 3D physical model, PC image viewed through a head-mounted display).

Methodology

A quasi-experimental study was selected as a means to perform the comparative analysis of spatial visualization ability during the spring of 2015. The study was conducted in an Engineering Graphics course offered as part of the Engineering Technology program.

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The participants from the study are shown in Figure 1. Using a convenience sample, there was a near equal distribution of participants between the three groups.

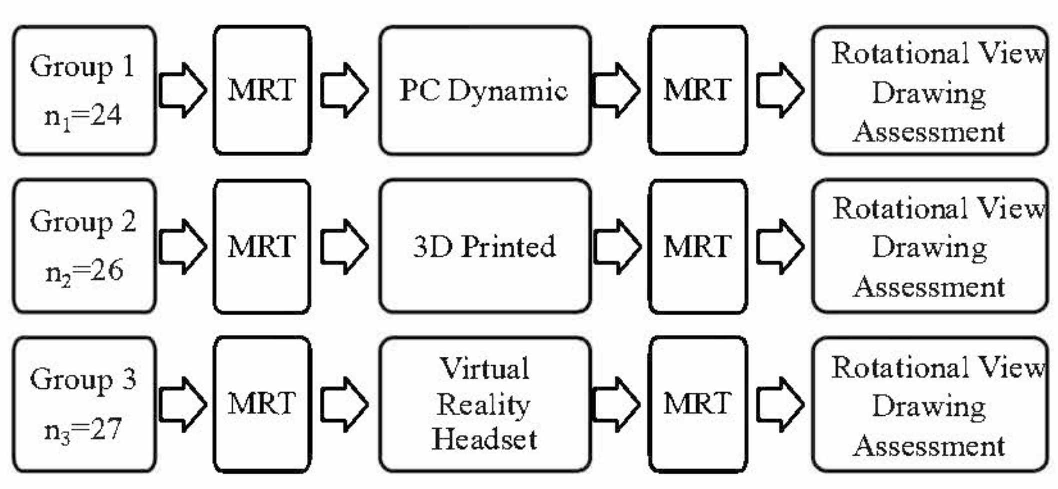

Figure 1. Research design methodology

The engineering graphics course emphasized hands-on practice using 3D AutoCAD software in the computer lab, along with the various methods of editing, manipulation, visualization, and presentation of technical drawings. In addition, the course included the basic principles of engineering drawing/hand sketching, dimensions and tolerance.

The students attended the course during the spring semester of 2015 and using a convenience sample they were divided into three groups. The three groups (*n1*=24, *n2*= 26 and *n3*=27, with an overall population of N = 77) were presented with a visual representation of an object (visualization) and were asked to create a rotational view. The first group (*n1*) received a 3D dynamic PC generated heptahedron visualization, self-rotated at 360 degrees at approximately four rounds per minute (slow rotation was used to prevent optical illusion and distortion of the original shape) during the creation of the rotational view (see Figure 2). The second group (*n2*) received a 3D dynamic printed heptahedron visualization, also self-rotated at 360 degrees at approximately four rounds per minute on top of a motorized base (see Figure 3). The third group (*n3*) received a 3D dynamic PC generated heptahedron visualization, viewed through a head-mounted display (Oculus) (see Figure 4), also self-rotated at 360 degrees at approximately four rounds per minute.

In addition, all groups were asked to complete the Mental Rotation Test (MRT) two days prior to completing the rotational view drawing and again right after, in order to identify the level and change of spatial visualization ability, and to show equality between the three groups. The MRT is one of the most commonly used instruments for measuring spatial ability (Caissie, Vigneau, & Bors, 2009). Reliability of the instrument has been

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found satisfactory; retest correlation was reported at .83 following an interval of one year or more (Vandenberg & Kuse, 1978). The MRT has been used to measure spatial abilities in relation to graphics and design curricula (Contero, Company, Saorin, & Naya 2006; Gorska & Sorby, 2008; Sorby, 2007). MRT consists of 20 items that require the learner to compare two-dimensional drawings and three-dimensional geometric figures. Developed by Vandenberg and Kuse (1978), the MRT assesses spatial visualization and mental rotation components. Each item on the MRT consists of five line drawings, which includes a geometrical target figure (criterion figure) on the left followed by two reproductions of the rotated target, as well as two distractors. The learner is required to indicate which two of the four represented are the actual rotated replicas of the geometrical target figure on the left (Caissie et al., 2009; Gorska & Sorby, 2008). The learner has a time constraint of four minutes for the first ten items, and after a short break, four minutes are given to solve the remaining ten.

Upon completion of the MRT, the course instructor presented the first group (*n1*) with a projection of a PC generated dynamic visualization of the heptahedron and asked them to create a rotational view of it (see Figure 2). The students in the first group (*n1)* were able to approach the visualization and observe from a close range.

For the second group (*n2*), the instructor presented students with a 3D printed dynamic visualization of the heptahedron and asked them to create a rotational view of it (see Figure 3). Students in the second group *(n2)* also had the privilege of close observation.

Group 3 *(n3)* was asked to use the Oculus Virtual Reality head-mounted display to create a rotational view of the dynamic visualization of the heptahedron that was projected inside (see Figure 4).

All groups were given the same amount of time (five minutes) to observe the visualization model. This process took into consideration research that indicates a learner's visualization ability and level of proficiency can easily be determined through sketching and drawing techniques (Contero et al., 2006; Mohler, 1997).

The engineering hand sketch used in this research was a rotational view of the heptahedron. Rotational views are very useful engineering graphics tools, especially for parts that have complex interior geometry, as the sections are used to clarify the interior construction of a part that cannot be clearly described by hidden lines in exterior views (Plantenberg, 2012). The rubric included the following parts: (a) right orientation of axis, (b) use of correct proportion, (c) accurate angle used for isometric perspective, (d) appropriate use of visible lines, and (e) appropriate use of drawing space. The maximum score for the drawing was 6 points (see Figure 5 for rotational views of the Heptahedron).

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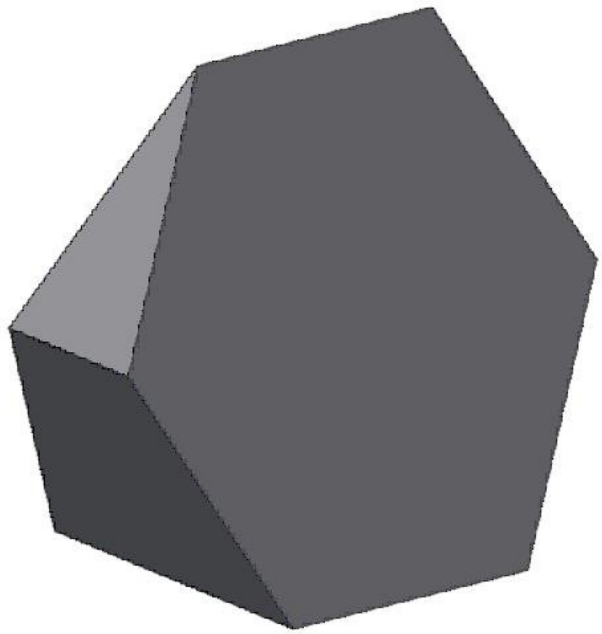

Figure 2. Group 1 was able to view the heptahedron using a 3D PC generated dynamic visualization

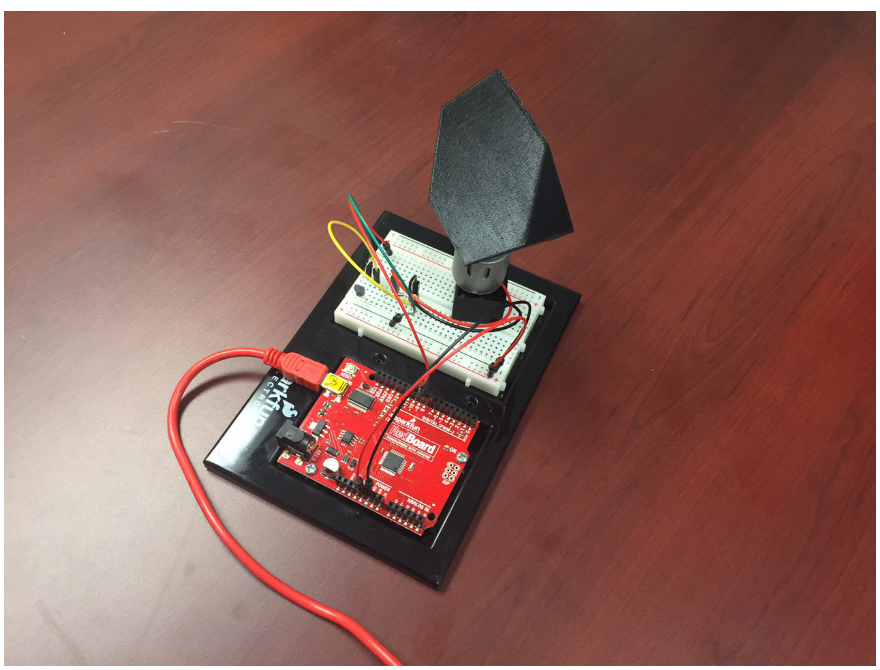

Figure 3. Group 2 was able to view the heptahedron using a 3D printed dynamic visualization

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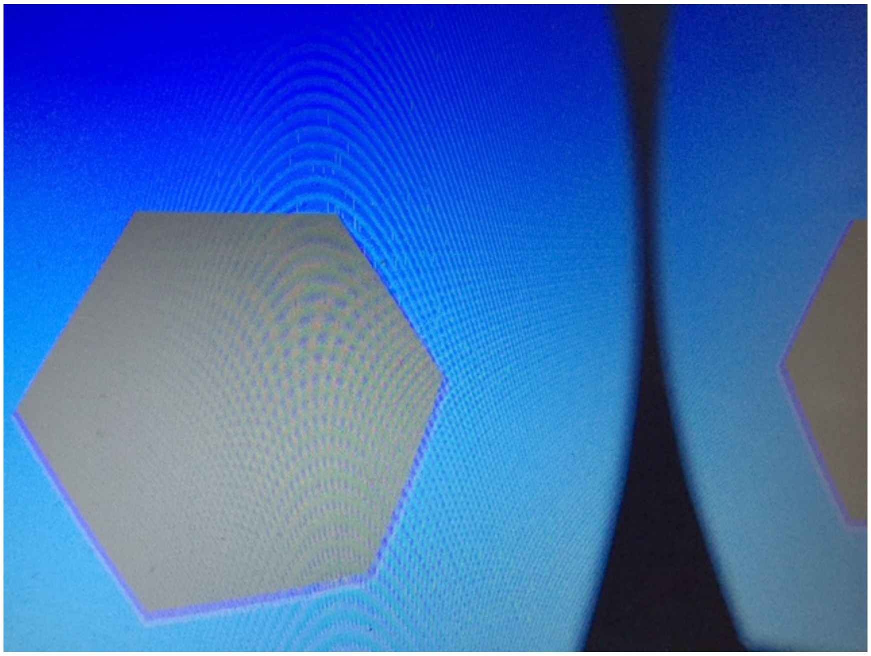

Figure 4. Group 3 was able to view the heptahedron using the Oculus Virtual Reality head-mounted display

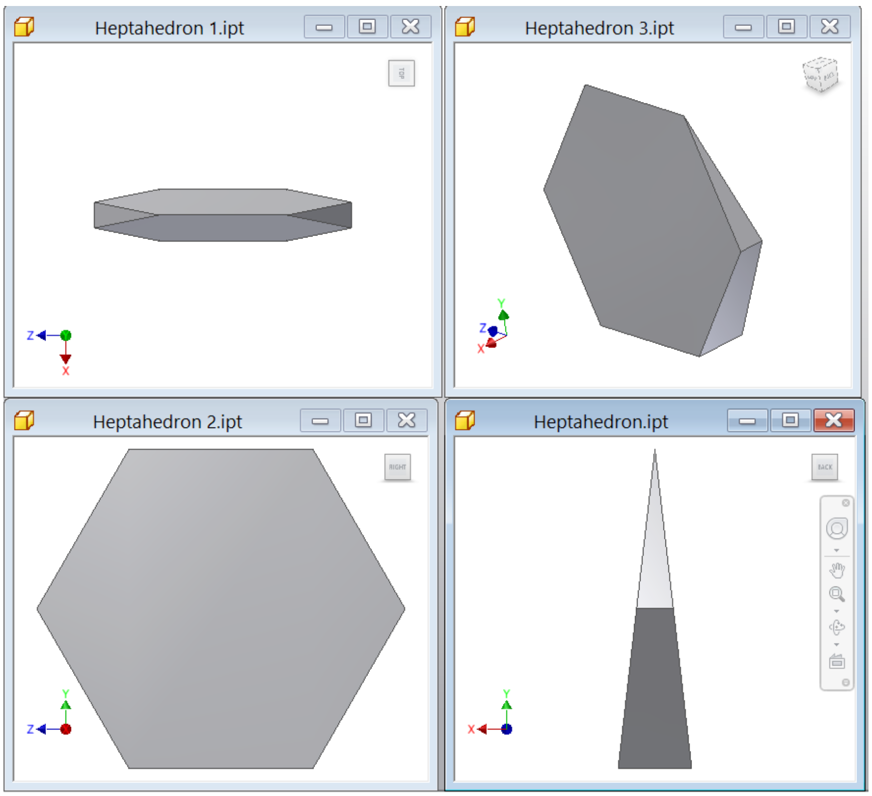

Figure 5. Rotational views of the heptahedron model

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Data Analysis

Analysis of MRT Scores

The first method of data collection involved the completion of the MRT instrument before (to show existing level of spatial ability) and after the treatment to show different spatial ability levels between the three different groups. The researchers graded the MRT instrument, as described in the guidelines by the MRT creators. A standard paper-pencil MRT was conducted, in which the subjects were instructed to choose the correct rotational view from the ones presented. The maximum score that could be received on the MRT was 20. As it can be seen in Table 2 for the pre-test, n1 had a mean of 18.792, n2 had a mean of 18.462, and n3 had a mean of 18.815. As far as the post-test n1 had a mean of 19.698, n2 had a mean of 19.042, and n3 had a mean of 19.348 (see Table 1).

Due to the relatively low numbers of the participants and the fact that we did not have random samples, a non-parametric Kruskal-Wallis test was run to compare the mean scores for significant differences, as it relates to spatial skills among the three groups. The result of the Kruskal-Wallis test, as shown in Table 2, was not significant $X^2= 1.341$, $p < 0.321$.

Table 1
MRT Descriptive Results

Models	N	Mean pre-test	Mean post-test	SD pre-post	SE pre-post	95% Confidence Interval for Mean Lower Bound pre-post	95% Confidence Interval for Mean Upper Bound pre-post
PC Dynamic	24	18.792	19.698	3.7181	.7590	18.222	19.362
3D Printed Dynamic	26	18.462	19.042	3.9011	.7651	18.886	18.237
Oculus	27	18.815	19.348	6.1958	1.1924	18.564	19.266
Total	77	18.356	19.362	4.8054	.5476	18.557	18.955

Table 2
MRT pre and post-test Kruskal-Wallis H test Analysis

Models	N	DF	Mean Rank	X^2	P-value
PC Dynamic	24	2	18.80	1.341	.321
3D Printed Dynamic	26		19.82		
Oculus	27		18.26		
Total	77				

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Analysis of Drawing

The second method of data collection involved the creation of a rotational view drawing. As shown in Table 3, the group that used the 3D printed Model (*n* =26), had a mean observation score of 5.154. The groups that used the PC computer generated model (*n=24*) or the Virtual Reality head-mounted display (*n* = 26) had lower scores of 4.667 and 4.296, respectively (see Table 3). A Kruskal-Wallis test was run to compare the mean scores for significant differences among the three groups. The result of the Kruskal-Wallis test, as shown in Table 4, was significant: X^2= 1.121, $p < 0.0049$. The data was dissected further through the use of a post hoc *Steel-Dwass* test. As it can be seen in Table 5, the post hoc analysis shows a statistically significant difference between the 3D printed vs. PC generated dynamic model ($p < 0.032$, $d = 0.4571$, Z=2.3420) and the 3D printed vs. Oculus ($p = 0.001$, $d = 0.8417$, Z=2.0815).

Table 3
Rotational View Drawing Descriptive Results

					95% Confidence Interval for	
	N	Mean	SD	Std. Error	Lower Bound	Upper Bound
PC Dynamic	24	4.667	.6370	.1300	4.398	4.936
3D Printed	26	5.154	.6748	.1323	4.881	5.426
Oculus	27	4.296	.7753	.1492	3.990	4.603
Total	77	4.701	.7791	.0888	4.524	4.878

Table 4
Rotational View Kruskal-Wallis H test Analysis

Models	N	DF	Mean Rank	X^2	P-value
PC Dynamic	24	2	17.92	1.121	.0049
3D Printed Dynamic	26		19.79		
Oculus	27		16.92		
Total	77				

Table 5
Rotational View Drawing Steel-Dwass test Results

	Visual Aids (1 vs. 2 vs. 3)	Score Mean Diff.	Std. Error	*Z*	*p*
2 vs 1	3D Printed vs. PC Dynamic	0.4751	0.1872	2.3420	0.032*
2 vs 3	3D Printed vs. Oculus	0.8417	0.1982	2.0815	0.001*
3 vs 1	Oculus vs. PC Dynamic	-0.2531	0.1981	1.0381	0.102

* Denotes statistical significance

Discussion

This study was done to determine if there is a difference in spatial visualization ability and the impacts of Virtual Reality head-mounted displays on dynamic visualizations for engineering technology students. In particular, the study compared the use of different visual models: a 3D printed solid dynamic visualization, a 3D computer generated visualization, and a 3D printed dynamic visualization viewed through a Virtual Reality head-mounted display (Oculus). It was found that the use of the Virtual Reality head-mounted display provided no statistically significant higher scores over the other two types of visual models; therefore, the hypothesis that there is significant effect in spatial visualization ability due to the mode of displaying a rotating 3D geometric shape (PC image, 3D physical model, PC image viewed through a head-mounted display) on students': a) Spatial visualization ability as measured by the MRT and b) ability to sketch a rotational view drawing was rejected.

The fact that none of the groups gained any statistically significant advantage from the use of virtual reality head-mounted displays over other conventional types of models could suggest that the geometrical shape used for this study (heptahedron) was not complex enough to promote additional gains that a virtual reality head-mounted display could offer. The use of Virtual Reality (VR) head-mounted displays (HMDs) can also produce temporary deficits of binocular vision (Mon-Williams, Warm, & Rushton, 1993). Numerous reports exist that show adverse visual symptoms following use of VR systems (Regan & Price 1994). Mon-Williams et al. (1993) showed that these symptoms are associated with changes in the visual system. According to Mon-Williams et al. (1993), various causal mechanisms related to headset engineering explain the observed change in heterophoria (the bias that exists in the vergence eye movement system under open-loop conditions) after VR HMD use. According to Mon-Williams et al. (1993), an additional cause of visual stress, which has not been previously identified with regard to Virtual Reality systems, is the change in the vertical gaze angle. Gaze angle (the vertical orientation of the eyes with respect to the head) is changed, so the effort of the extra-ocular muscles is modified (Heuer & Owens, 1989; Heuer, Wischmeyer, Bruwer,

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& Romer, 1991). Therefore, it could be suggested that one of the reasons the Virtual Reality head-mounted displays did not provide statistically significant higher scores over the other two types of visual models was that during treatment the students experienced temporary deficits in binocular vision that could result in errors during the rotational view drawing process. An additional reason it could be the fact that the treatment only lasted for a short time and it was not enough to make significant gains in spatial ability.

Interestingly enough, even though it is not statistically significant, during the Kruskal-Wallis test, the Steel-Dwass post hoc test revealed that the groups who received treatment via 3D printed vs. Oculus ($p=0.001$), followed by the group that received treatment via 3D printed vs. PC dynamic ($p=0.032$), had significant differences in between. This result could suggest that the virtual reality head-mounted display technology is a new, unfamiliar technology that can favor specific populations based on their level of spatial skills. Hegarty and Waller (2005) suggest that individuals with high spatial abilities benefit from more complex visualizations because they already have effective mental models to process 3D information versus individuals with lower spatial abilities who lack these effective mental models.

Limitations and Future Plans

In order to have a more thorough understanding of the effects on spatial visualization ability of head-mounted displays for engineering technology students, as measured through rotational view drawings, and to understand the implications for student learning, it is imperative to consider further research. Future plans include, but are not limited to:

- repeating the study using a larger population to verify the results.
- repeating the study using a different population such as mathematics education, science education, or technology education students.
- repeating the study by comparing male versus female students.
- repeating the study and extending the time of treatment.

References

Abulrub, A.G., Attridge, A., & Williams, M.A. (2011). Virtual reality in engineering education: The future of creative learning. Paper presented at the International Conference IEEE EDUCON2011, April 2011 at Princess Sumaya University for Technology in Amman, Jordan.

Beattie, N., Horan, B., & McKenzie, S. (2015). Taking the LEAP with the Oculus HMD and CAD – plucking at thin air? *Procedia Technology*, 20(2015), 149-154.

Burdea, G. (2004). Teaching Virtual Reality: Why and How? *Presence: Teleoperators and Virtual Environments*, 13, 463-483.

Burdea, G. (2008). World-wide survey of universities teaching virtual reality. Retrieved on October 19th, 2015, from http://vrtechnology.org/resources/public/survey.html

ISSN: 1949-9167

Callaghan, M.J., McCusker, K., Lopez-Losada, J., Harkin, J.G., & Wilson, S. (2009). Engineering education island: Teaching engineering in virtual worlds. *Innovations in Teaching & Learning in Information & Computer Sciences*, 8(3), 2-18.

Caissie, A.F., Vigneua, F., & Bors, D.A. (2009). What does the mental rotation test Measure? An analysis of item difficulty and item characteristics. *The Open Psychology Journal*, 2009, 2, 94-102.

Chen, C.J. (2006). Are spatial visualization abilities relevant to virtual reality? *Journal of Instructional Science and Technology*, 9(2), 1-16.

Cohen, C.A. & Hegarty, M. (2014). Visualizing cross sections: Training spatial thinking using interactive animations and virtual objects. *Learning and Individual Differences*, 33, 63-71.

Contero, M., Company, P., Saorin, J., & Naya, F. (2006). Learning support tools for developing spatial abilities in engineering design. *International Journal of Engineering Education*, 22(3), 470-477.

Fillatreau, P., Fourquet, J.Y., Le Bolloc'h, R., Cailhol, S., Datas, A. & Puel, B. (2013). Using virtual reality and 3D industrial numerical models for immersive interactive checklists. *Computers in Industry, 64*(2013), 1253-1262.

Flanders, M. & Kavanagh, R.C. (2013). Visualizing compound rotations with virtual reality. *Engineering Design Graphics Journal, 77*(3), 15-30.

Freina, L. & Ott, M. (2015). A literature review of immersive virtual reality in education: State of the art and perspectives. The 11th International Scientific Conference eLearning and Software for Education, Bucharest, April 23-24, 2015.

Gorska, R. & Sorby S. (2008). Testing instruments for the assessment of 3-D spatial skills. *Proceedings from the American Society for Engineering Education (ASEE) Annual Conference*, Pittsburgh, PA, June 22-25, 2008.

Häfner, P., Häfner, V., & Ovtcharova, J. (2013). Teaching methodology for virtual reality practical course in engineering education. *Procedia Computer Science, 25*(2013), 251-260.

Hegarty, M. & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. Intelligence, 32, 175-191.

Heuer, H. & Owens, D.A. (1989). Vertical gaze direction and the resting posture of the eyes. *Perception, 18*(3), 363-377.

Heuer, H., Wischmeyer, E., Bruwer, M., & Romer, T. (1991). Apparent size as a function of vertical gaze direction: New tests of an old hypothesis. *Journal of Experimental Psychology: Human Perception and Performance, 17*(1), 232-245.

Lee, E.A. & Wong, K.W. (2014). Learning with desktop virtual reality: Low spatial ability learners are more positively affected. *Computers & Education, 79*(2014), 49-58.

Maier, P. H. (1994). Raeumliches vorsellungsvermoegen. Frankfurt a.M., Berlin, Bern, New York, Paris, Wien: Lang.

Martín-Gutiérrez, J., García-Domínguez, & Roca-González, C. (2015). Using 3D virtual technologies to train spatial skills in engineering. *International Journal of Engineering Education, 31*(1B), 323-334.

McGee, M. G. (1979). Human Spatial Abilities: Psychometric Studies and Environmental, Genetic, Hormonal, and Neurological Influences. *Psychological Bulletin*, *86*(5), 889–918.

Mohler, J.L. (1997). An instructional method for the AutoCAD modeling environment. *Engineering Design Graphics Journal, 61*(1), 1-11.

Mon-Williams, M., Warm, J.P., & Rushton, S. (1993). Binocular vision in a virtual world: Visual deficits following the wearing of a head-mounted display. *Ophthalmic and Physiological Optics, 13*(4), 387-391.

Oxford Dictionaries (2015). Virtual reality definition. Retrieved on November 26th, 2015, from http://www.oxforddictionaries.com/us/definition/american_english/virtual-reality

ISSN: 1949-9167

Parkin S. (2014). Oculus Rift. Retrieved on Febraury18th, 2016, from https://www.technologyreview.com/s/526531/oculus-rift/

Plantenberg, K. (2012). *Engineering graphics essentials with AutoCAD 2013 Instruction.* SDC Publications: Mission, Kansas.

Rafi, A., Anuar, K., Samad, A., Hayati, M., & Mahadzir, M. (2005). Improving spatial ability using a web-based virtual environment (WbVE). *Automation in Construction, 14*(2005), 707-715.

Rafi, A., Anuar-Samsudin, K, & Soh-Said, C. (2008). Training in spatial visualization: The effects of training method and gender. *Educational Technology & Society, 11*(3), 127-140.

Regan, E.C. & Price, K.R. (1994). The Frequency of Occurrence and Severity of Side-Effects of Immersion Virtual Reality. *Aviation, Space, and Environmental Medicine, 6,* 527-530.

Sorby, S.A. (2007). Developing 3D spatial skills for engineering students. *Australasian Journal of Engineering Education, 13*(1).

Sorby, S.A. & Baartmans, B.J. (2000). The development and assessment of a course for Enhancing the 3-D spatial visualization skills of first year engineering students. *Journal of Engineering Education, 89*(July), 301-307.

Sorby, S.A. & Baartmans, B.J. (1996). A course for the development of 3-D spatial visualization skills. *Engineering Design Graphics Journal, 60*(1), 13-20.

Tibola, L., Pereira, C.E. & Tarouco, L.M.R. (2014). Improving performance to engineering students through virtual labs and its monitoring in cockpit. *International Journal of Engineering Pedagogy, 4*(4), 43-50.

Vandenberg, S.G. & Kuse, A.R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills, 47,* 599-604.

Yurt, E. & Sünbül, A.M. (2012) (1987-1992). Effect of modeling-based activities developed using virtual environments and concrete objects on spatial thinking and mental rotation skills. *Educational Sciences: Theory & Practice*, *12*(3).

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