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

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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).

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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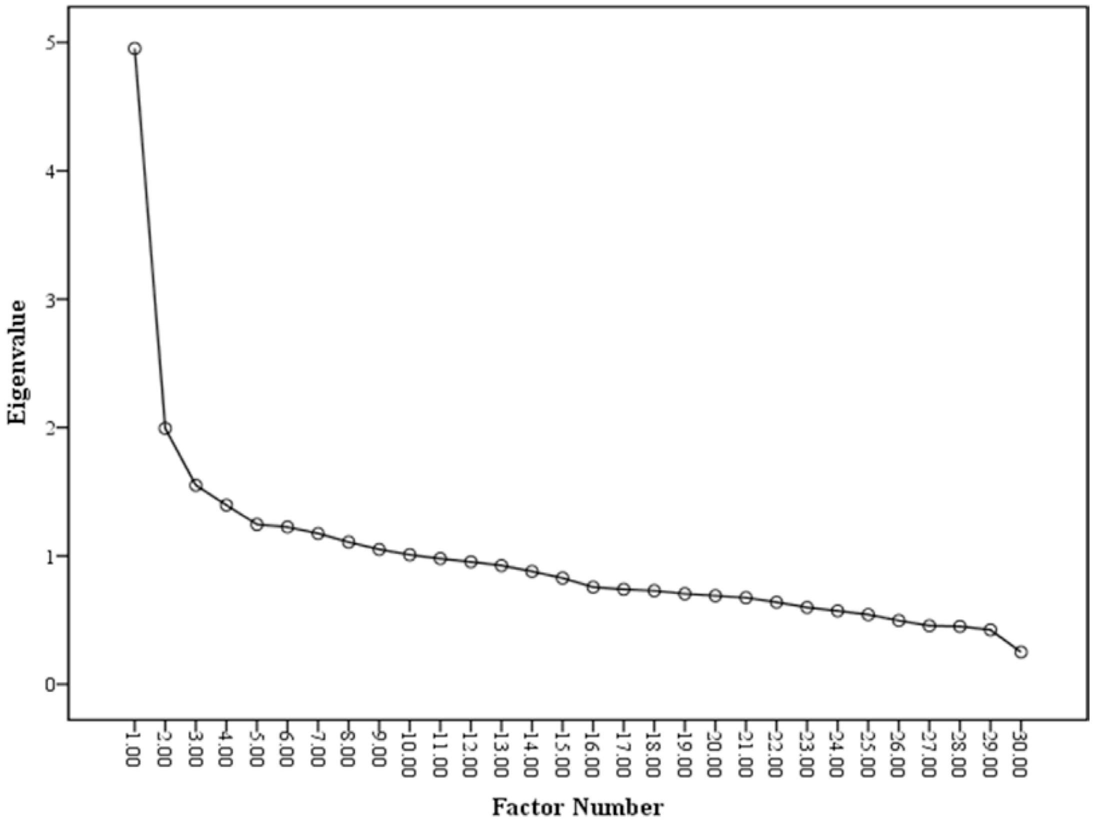

Figure 1. Results of the scree test with eigenvalues

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

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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.

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Note

Preliminary results of this study were presented at the 2016 ASEE Midyear Conference proceedings in Daytona Beach, FL

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