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# Using EFA to Determine Factor Structure of a Computer-Based Version of the Purdue Spatial Visualization Test: Rotations (PSVT:R)

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## Abstract

Literature shows that spatial skills, and in particular, mental rotation skills, are predictors of success in STEM. Students who have strong spatial visualization skills are more likely to demonstrate better academic performance and higher retention rates in STEM. Several instruments are used to measure mental rotation skills, most of which are paper-based; these include the Mental Rotations Test (MRT), Rotated Colour Cube Test (RCCT), and Purdue Spatial Visualization Test: Rotations (PSVT:R). To measure the range of skills typically seen in undergraduate engineering students, the PSVT:R has been historically preferred for its use of a variety of 3-dimensional shapes, which are appropriately challenging to visualize, and for its established reliability and validity. A data-rich computer-based version of the test offers several advantages over the paper-based test; however, its reliability and validity must be established. We present the analysis of the results of a computer-based version of the PSVT:R administered to first-year engineering students at a mid-sized, public university in the United States. We use an exploratory factor analysis (EFA) to determine the number of latent variables being measured by the instrument in our data. We determine the number of latent variables to be one, with good reliability, which is consistent with the paper-based instrument. In future work, we plan to use a confirmatory factor analysis (CFA) to show evidence of validity of the computer-based PSVT:R.

## Introduction

It is well-established in literature that spatial skills are strongly correlated with academic success in STEM. In particular mental rotation (MR) has been shown to correlate with course grades and retention in engineers [1], [2]; however, it has also been shown that factors such as gender [3], cultural background [4], and even socioeconomic status [5] impact spatial skills, putting groups already underrepresented in STEM at a disadvantage. Fortunately, spatial skills can be taught and have been linked to improved performance in STEM courses [6]–[10]. Thus, as a part of the greater movement to diversify the students graduating with degrees in engineering, we aim to collect evidence of validity for a commonly used assessment of mental rotation ability that has been adapted to a digital environment.

Different instruments have been used in literature to measure subjects' mental rotation ability, such as the Mental Rotations Test [11], the Rotated Colour Cube Test [12], and the instrument used here, the Purdue Spatial Visualization Rest: Rotations (PSVT:R). We assess our students using this instrument due to its appropriate difficulty level, as well as its resistance to solution via analytical methods (e.g., box-counting). Because of the opportunity for a more data-rich assessment, prior work had developed an online version of the PSVT:R [6]. It is necessary to complete separate assessments of paper-based and computer-based tests, even if they are otherwise identical, as instruments show marked difference in their results when given via different platforms [13].

Psychrometric properties of the paper-based PSVT:R have been studied with evidence of validity [14], although more recent work has highlighted disparities in the number of factors present [15]–[17], ambiguities with the presentation of the figures [18], and validity of the concept of spatial skills as a whole [19]. We address only the foremost issue here, using accuracy data acquired from one cohort of first-year engineering students; however, we differ slightly in our methods from previous works by removing learning items from the factor analysis to address the following research question: *what is the underlying factor structure of a computer-based version of the PSVT:R?*

## Methods

### *Participant Inclusion Criteria*

Participants were first-year undergraduate engineering students at a single, mid-sized, public, East Coast university in 2016. They were 18+ years of age at administration of the test and consented to being part of the study.

### *Data Collection*

The instrument used is an online version of the Revised PSVT:R. A screenshot of this program can be seen in Figure 1.

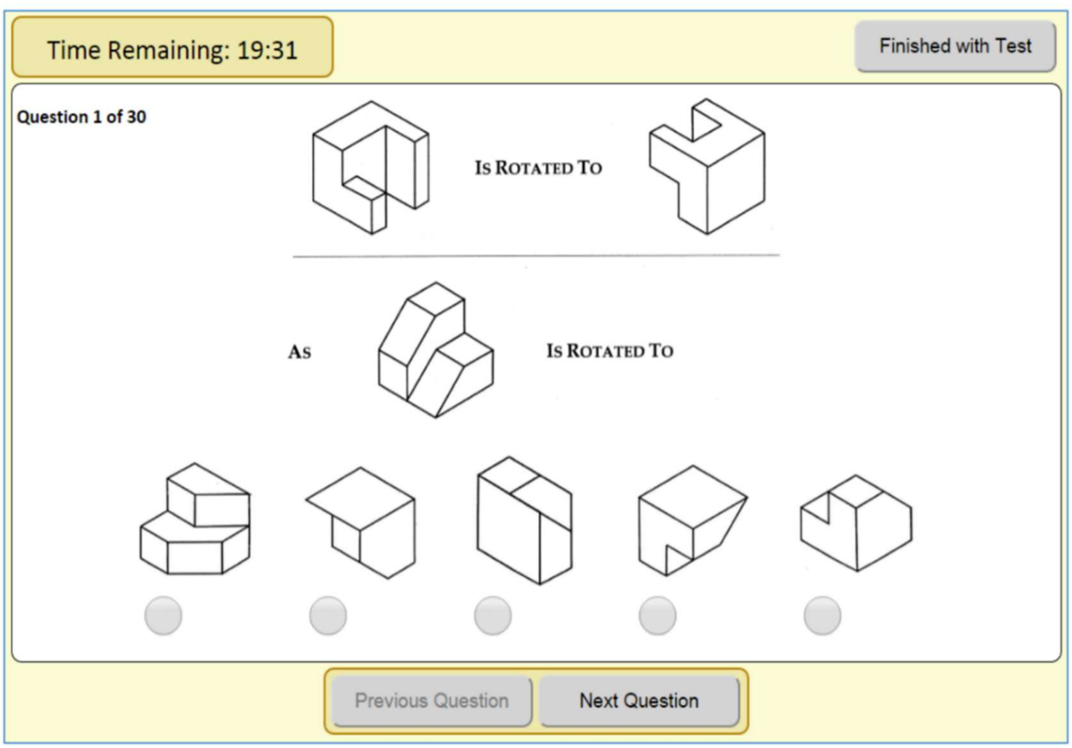


*Figure 1. A screen capture of the layout of the computer-based PSVT:R program*

Students were informed about the number of questions (30 items) and time limit allowed (20 minutes), shown two example problems as a group, and then permitted to begin at their leisure. (Timers are individual.) Problems are presented in the original order, one at a time, with the prompt and multiple-choice responses both visible simultaneously. Guessing does not count against the students, but they are allowed to skip questions as desired. If the students finish the last question before their time is up, they are allowed to review their responses and/or submit early. At the end of the time limit, the test automatically submits. The collective dataset was gathered over the course of one week at the beginning of the fall semester.

### *Data Cleaning*

Students who were not in their first semester of university and/or were transfer students were removed from the study, as well as students who had taken the PSVT:R prior to the assigned testing time. Students who completed the test in under 5 minutes were also removed, as it was assumed the student did not put forth their best effort, as all tests completed within this time span only reached chance accuracy. Unanswered questions (missing data) were dealt with by marking the missing items as 'incorrect', because students were either 1) told if they had left questions unanswered when they attempted to submit their test early and purposefully decided to skip items or 2) timed out of the test and had never reached the unanswered items. Initial data analysis prompted the exclusion of Items 1-4 (out of 30) as training items, due to very high inter-item correlations and small percentage of subjects answering incorrectly.

### *Computation*

SPSS v29 was used to conduct the analyses and produce figures. Default settings are used, except where stated otherwise. We employ an exploratory factor analysis (EFA) of the accuracy data for the 26 remaining items to determine the number of factors present. We first ensure that no items correlate strongly enough to warrant removing one. Then, we run an EFA that allows an unlimited number of factors, enabling us to see how much of the variance can be accounted for by studied latent variables. Finally, we run one or more EFAs with a set number of factors, informed by the scree plot, comparing the fits between models, and removing items that do not load appropriately. This process is repeated until a stable solution is found.

### *IRB Approval*

This study was approved by Rowan University's Institutional Review Board, Pro2017001804.

## Results & Interpretation

### *Descriptive Statistics*

The 180 valid responses left after data cleaning are included in this analysis. The total score, or the total number of items answered correctly by a student, out of 26, ranged from 3 to 26, with a mean of 17.8 and a standard deviation of 4.8. Both the skewness and kurtosis of the total score variable were found to be between -0.5 and 0, implying normality of that data. The means of the items (possible values 0 & 1) ranged from 0.23 to 0.91, representing the percentage of students who answered that item correctly. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was 0.71, indicating that the data were appropriate to continue with the selected analysis. Bartlett's test of sphericity was found to be significant ($p<.001$), indicating sufficient correlation between variables to move forward.

### *Exploratory Factor Analysis – Phase 1*

In this first round of analysis, 8 factors were found to have eigenvalues above 1, with a cumulative explained variance of 53.9%. (Example data format can be found in the appendix.) As stated prior, literature conflicts in its opinion of how many factors are present. At creation, the PSVT:R was intended to only have one factor, mental rotation skill [20]; however, to the authors' knowledge, there was no theoretical reason given as to why only one factor should be present. For these reasons, a scree plot was consulted to determine a narrower range of factors that are present in our data, shown in Figure 2.

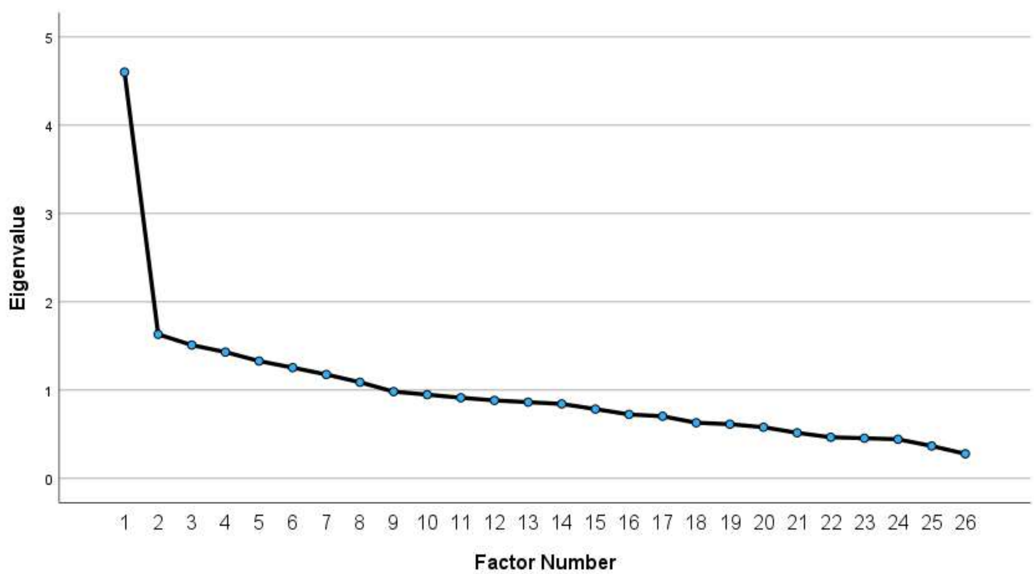


*Figure 2. Scree plot of eigenvalues seen in our 26-item version of the PSVT:R*

The scree plot of eigenvalues implied that there is 1 factor present in our data. For thoroughness, we also assess the 2-factor model of the data. Cronbach's alpha was found to be good at 0.807 [21], with no singular item removal increasing this value by more than 0.002.

In a 1-factor model with a factor matrix cutoff of 0.3, we find that items 9, 18, 24, and 30 do not load sufficiently. Due to being a one-factor solution, rotation was not applied. This model accounted for 17.7% of the variance in the data.

In an unrotated 2-factor model, we find that the same 4 items as seen in the 1-factor model did not sufficiently load; in addition, in the 2-factor model, 3 items are now found to cross-load. Neither varimax nor direct oblimin rotation improved the number of items with sufficient loadings or cross-loadings. The 2-factor model accounted for 24.0% of the variance in the data.

### *Exploratory Factor Analysis – Phase 2*

Phase 2 of the EFA begins with the removal of items which did not sufficiently load; here, items 9, 18, 24, and 30 were removed, resulting in a 22-item version of the PSVT:R. A scree plot is again consulted, shown in Figure 3.

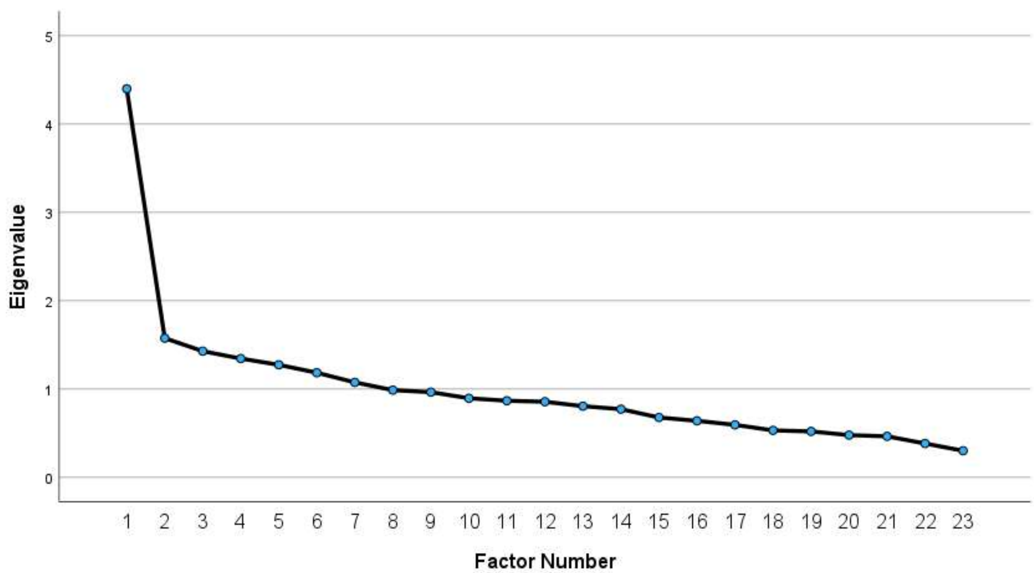


*Figure 3. Scree plot of eigenvalues seen in our 22-item version of the PSVT:R*

Again, the scree plot suggests considering the 1- and 2-factor models of the data. KMO and Bartlett's test values are still sufficient, at 0.73 and $p$ <.001, respectively. A Cronbach's alpha value of 0.0802 indicates good internal consistency [21], with no singular item deletion raising that value.

A 1-factor model accounts for 19.7% of the variance and shows sufficient loading on all 22 items with a 0.3 cutoff. We argue that this is the best model for our data.

An unrotated 2-factor model accounts for 26.7% of the variance, with all items loading sufficiently onto the first factor; however, 3 items still cross-load onto the second factor. A direct oblimin rotation does not improve the model. A varimax rotation produces an interesting result; all items except Items 5 and 26 load cleanly onto 2 factors, as shown in Table 1.

*Table 1. Varimax rotated factor matrix for 22-item PSVT:R*

| *Item* | Factor 1 | Factor 2 |
|---|---|---|
| *5* | | |
| *6* | .342 | |
| *7* | .386 | |
| *8* | | .313 |
| *10* | | .380 |
| *11* | | .335 |
| *12* | .391 | |
| *13* | | .342 |
| *14* | | .311 |
| *15* | .314 | |
| *16* | .454 | |
| *17* | .324 | |
| *19* | .583 | |
| *20* | .628 | |
| *21* | .395 | |
| *22* | | .563 |
| *23* | | .334 |
| *25* | | .462 |
| *26* | .346 | .340 |
| *27* | .306 | |
| *28* | | .426 |
| *29* | | .344 |

Had the 1-factor model of the 22-item PSVT:R not resulted in a clean outcome, the varimax 2-factor model of the 22-item PSVT:R would have been carried forward to further iterations of EFA. The fact that both can be argued for in the same data set reflects the disparity in literature about how many factors are present. This requires further study.

Additionally, it should be noted that 3 of the 4 items removed between the first and second rounds of EFA (Items 9, 18, & 24) are 3 of 4 items in the PSVT:R (Items 6, 9, 18, & 24) with figures that have curved surfaces. This observation deserves further consideration in future work.

**Conclusions**

We studied the factor structure of an online version of the PSVT:R using accuracy data from first-year undergraduate engineering students. We argue that our data is best represented by the 22-item, 1-factor model of the PSVT:R, but also acknowledge that evidence of a second factor may be present.

## Limitations

The data used in this paper came from one cohort of first-year engineering students at a single university, severely impacting generalizability. Additionally, the sample size of N=180 was somewhat small to analyze an instrument of 26 items. Further, this analysis was done in SPSS, which does not support the WLSMV estimator, which is most appropriate when analyzing binary data. We also set the factor matrix cutoffs at 0.3, rather than the preferred 0.4, due to many of the items not loading onto any factor at the 0.4 level. We hope to remedy or reduce the impact of these limitations in future analyses.

## Future Work

In this ongoing study, we plan to collect further evidence of validity for the PSVT:R as a test of mental rotation skill in engineering undergraduates, using a larger dataset spanning multiple years and employing a more robust estimator. We also intend to conduct a confirmatory factor analysis on this larger dataset, as well as incorporate item response time into our analysis to separate speed-related variance.


## Acknowledgements

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**Appendix**

*Table 2. Example data format used in EFA, where 0 is incorrect/unanswered and 1 is correct*

| Subject Identifier | Q5 Accuracy | Q6 Accuracy | Q7 Accuracy | … | Q30 Accuracy |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 0 | … | 1 |
| 2 | 1 | 0 | 1 | … | 0 |
| 3 | 1 | 1 | 1 | | 0 |