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The Relationship Between Students' Ability to Model Objects from Assembly Drawing Information and Spatial Visualization Ability as Measured by the PSVT:R and MCT

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Abstract

During the Fall 2012 semester a study was conducted in a junior-level constraint-based modeling course to determine the relationship between students' ability to create solid models when given an assembly drawing and their spatial visualization ability. Students were administered the PSVT:R and the MCT and were then given an assembly drawing and asked to model as many of the seven parts as possible during a 110 minute class period. The parts in the assembly ranged in complexity from a ball to a valve body. Students were given a ruler to measure parts on the B-size drawing and determine sizes of features based on the given scale (2:1). Relationships were examined between the PSVT:R, MCT, modeling activity, final project and the final exam. This paper will present the results of this study and discuss implications for future research.

Introduction

With the reduced amount of instructional time for engineering graphics content in many engineering and technology programs, faculty have expressed concern that students' ability to visualize 3D parts from 2D drawings is not being developed as well as in the past[1-3]. More emphasis is being placed on learning the semantics of 3D modeling programs than on visualizing 3D objects from 2D drawings. With the increased emphasis on modeling and the decreased emphasis on interpreting engineering drawings, how well do students correctly model objects when given a 2D assembly drawing? How well does their modeling ability correlate with a standard measure of spatial visualization ability?

Measuring Spatial Abilities

Spatial abilities have been shown to be a predictor of success in several engineering & technology related disciplines [4]. Scores on spatial tests have also been used to predict success in engineering graphics courses [5-6]. Most studies involving engineering graphics students in the United States over the last 30 years have measured spatial ability using the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) [7]. The test is commonly used by engineering graphics faculty to measure this construct [8-12]. It is a 30 item timed test (20 minutes) of increasing difficulty appropriate for individuals 13 and older. Initial items require a rotation of 90 on one axis followed by items requiring 180 rotations about one axis, rotation of 90 about two axes, and finishing with items requiring rotation of 90 about one axis and 180 about another axis. An example problem is shown in Figure 1.

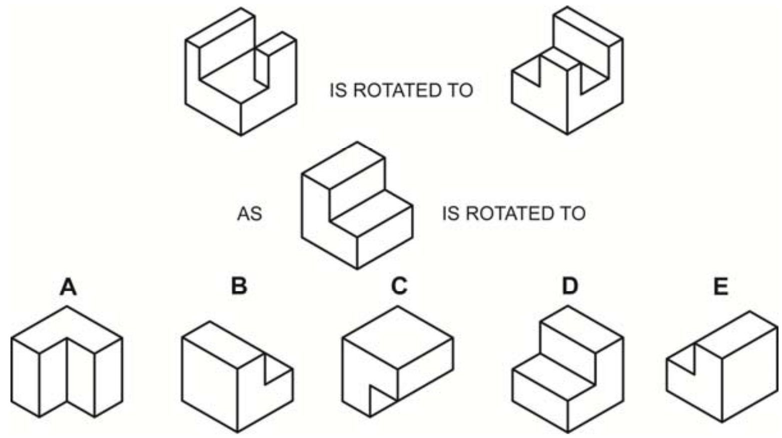

Figure 1. PSVT:R Example Problem.

When examining the international literature related to engineering graphics, the most common measure of spatial ability is the Mental Cutting Test (MCT) [13]. This timed instrument (20 minutes) consists of 25 items of increasing level of difficulty where students must visualize the cross sectional area of an object when given a cutting plane (Figure 2). It has been used to evaluate the effects of descriptive geometry on spatial ability [14], examine the effects of innovative solid simulators in engineering graphics courses [15], and predict success or failure in technical drawing courses [5].

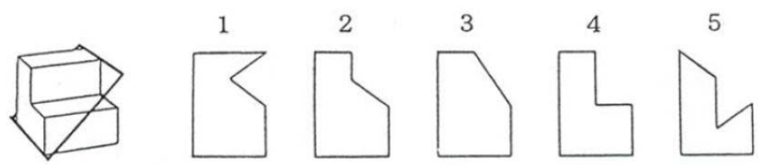

Figure 2. MCT Example Problem.

Previous Engineering Graphics Literacy Studies

During the Spring 2011 semester, a study was conducted at [name of university] in a junior-level constraint-based modeling courses where twenty-nine students were asked to model as many of the seven parts given in an assembly drawing of a device within a 110 minute class period (the modeling test) [16]. The main purpose of this pilot study was to determine the procedures necessary for this type of assessment in a classroom setting. The parts in the assembly ranged in complexity from a ball to a valve body. Students were given a ruler to measure parts on the B-size drawing and determine sizes of features based on the given scale (2:1). There was a positive relationship between the scores on the activity and the pace at which each student completed the parts. Only eight students modeled all seven parts in the assembly. Some of the students in the pilot study completely misinterpreted the 3D geometry of the parts. The researchers wondered if this was the result of insufficient practice reading drawings and/or the result of low spatial ability.

During the Fall 2011 semester, a similar study was conducted in two junior-level constraint-based modeling courses – one course at [name of university] (33 students) and the other course at [name of university] (35 students) [17]. There was a significant correlation between students' scores on the PSVT:R and their scores on the modeling test. The study did reveal that the PSVT:R may not be a good discriminator for spatial ability since a high percentage of students earned perfect scores.

For the current study the researchers wanted to continue to investigate how well current engineering and technology students read engineering drawings. Also of interest was examining the relationship between a different measure of spatial ability (e.g., the Mental Cutting Test) and the modeling test. The main research question for this study was "is a student's ability to interpret and model information from an assembly drawing related to their spatial visualization ability?" An additional research question was "how does this ability to read assembly drawings relate to other measures in the course (final project and final exam)?"

Participants

In the Fall 2012 semester, thirty-four students enrolled in a junior-level constraint-based modeling course at [name of university] participated in the study. The course consists of engineering graphics standards and conventional practices (sectional views, dimensioning, threads & fasteners, and working drawings), geometric dimensioning and tolerancing, and constraint-based modeling techniques (assemblies, advanced drawing applications, macros, design tables, and rendering). Tables 1-3 summarize demographic information on the participants.

Most of the students in the course were male from either engineering or technology, engineering & design education. Technology, engineering & design education students take the course as part of their major requirements, while other students typically take the course as part of a 5 course minor in Graphic Communications.

Table 1. Gender of Participants.

Gender	Frequency	Percent
Female	3	8.80%
Male	31	91.20%
TOTAL	34	100.00%

Table 2. Academic Year of Participants.

Year	Frequency	Percent
Sophomore	3	8.80%
Junior	16	47.10%
Senior	15	44.10%
TOTAL	34	100.00%

Table 3. Academic Major of Participants.

Major	Frequency	Percent
Art Studies	1	2.90%
Biomedical Engineering	1	2.90%
Business Administration	1	2.90%
Civil Engineering	1	2.90%
Engineering Undesignated	1	2.90%
Mechanical and/or Aerospace Engineering	5	14.70%
Technology, Engineering & Design Education	17	50.00%
TDE – Graphic Communications	6	17.60%
Textile Engineering	1	2.90%
TOTAL	34	100.00%

The Modeling Test – A Measure of Engineering Graphics Literacy

During the spring of 2011 several modeling tests were developed to assess students' ability to "read" or understand engineering graphics information. The tests were designed to include a wide range of elements such as threads, chamfers, fillets, grooves, and slots. From the computer models a multi-view assembly drawing with parts list was created for each practice test and the final modeling test. Figure 3 shows the modeling test used in this study.

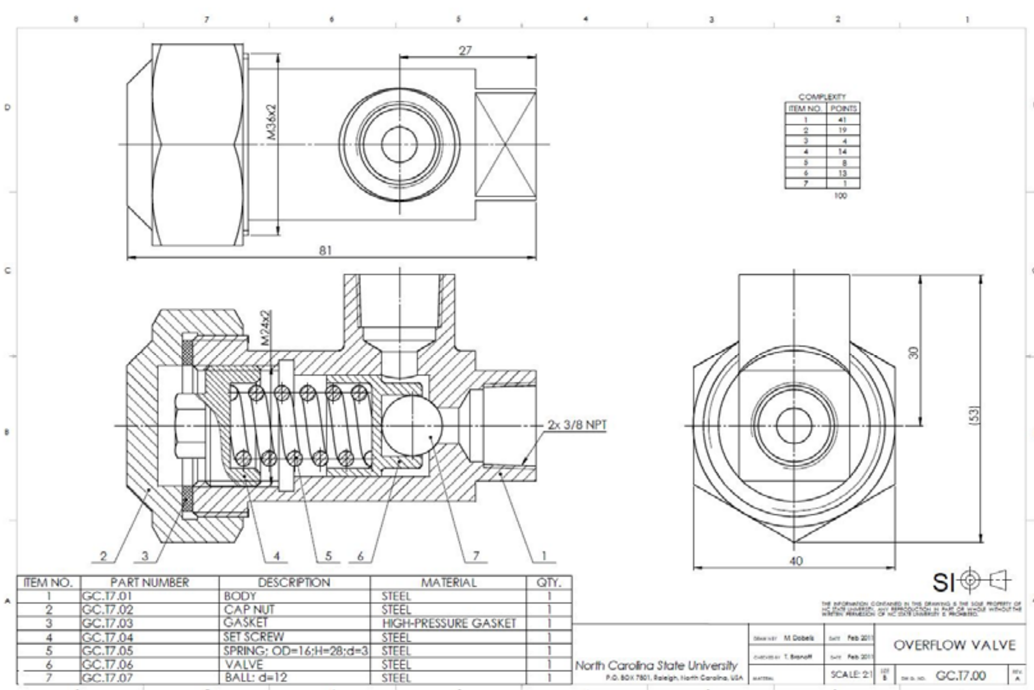

Figure 3. Example of the Modeling Test Drawing.

The metric system was used in the assembly drawing for the practice test and the modeling test. Both assemblies were created with a drawing scale of 2:1. Only overall dimensions and a few other dimensions required for installation were given, including thread designations and sizes. All of the information about the form and size of the parts had to be determined from the given views and sections and scaled with the use of a metric ruler. Integer millimeters for nominal dimensions were required for accuracy, and no fits, tolerances or surface finishes were required to be considered in the models. To measure the students' understanding of the assembly drawing, students were required to model the individual parts using 3D solid modeling software.

Final Project and Final Exam

Previous studies by the researchers compared the modeling test to other measures in the course such as the final project and the final exam. It was hypothesized that scores on the modeling test would be correlated with scores on the final project, but not necessarily with scores on the final exam. For the final project, students are assigned an assembly problem from the textbook. Assemblies typically range from 10-20 parts. Students are required to model all of the parts in the assembly, create a rendered image of the design, and then create a full set of working drawings for the project. The modeling required for the project is very similar to that in the modeling test. The final exam is comprehensive and covers material on the following topics: working drawings, solid modeling technique, engineering graphics standards and conventional practices, and geometric dimensioning and tolerancing. No modeling is required.

Methodology

During the 18th class meeting of the semester a class was dedicated to a practical exercise in reading assembly drawings. Since both the practice modeling test and the final modeling test were metric and included some European standards, a 15 minute lecture was given on how to read SI drawings. Students were then shown strategies for modeling parts in the example problem. After the lecture, students were given the rest of class to model as many parts as possible. During the 20th class meeting students were administered an electronic version of the PSVT:R and the MCT within the Moodle learning management system. Each test was set up to terminate after 20 minutes. During the next class meeting students were given the final modeling test assembly drawing and asked to model as many parts as possible during the 110 minute class period. Once the data was collected, one of the researchers evaluated all of the models produced by the students based on the rubrics pilot tested during the spring 2011 semester.

The Assessment Rubric

The assessment rubric spreadsheet was created to account for model accuracy and time required to model each part. Each feature and sketch (if any) was analyzed individually. Penalty points were assigned for each wrong geometric dimension including under-defined sketches. Penalty points were added for each dimension of the geometric primitive missing in the model, incorrect dimensions, and failure to correctly represent cosmetic threads.

Analysis of Results

The data was examined to see if there were identifiable differences in the means between the scores on the modeling test and the scores on the PSVT:R, MCT, final project, and final exam. Also of interest was the relationship between the PSVT:R and MCT. Figures 4-7 display scatterplots for these data to provide a visual representation.

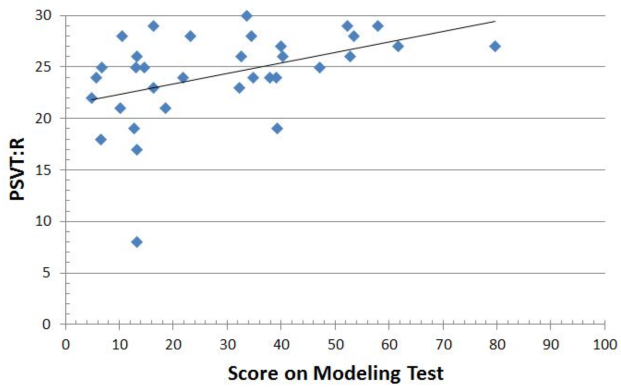

Figure 4. Modeling Test vs. PSVT:R.

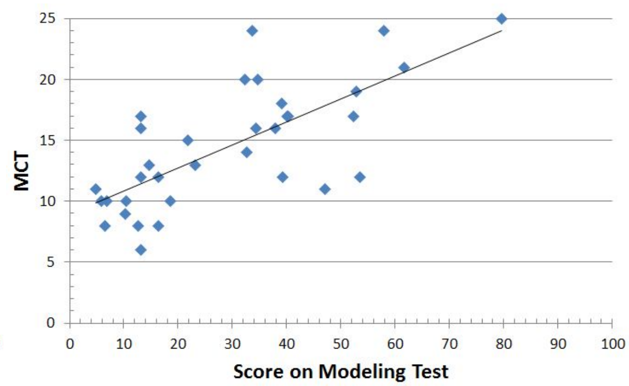

Figure 5. Modeling Test vs. MCT.

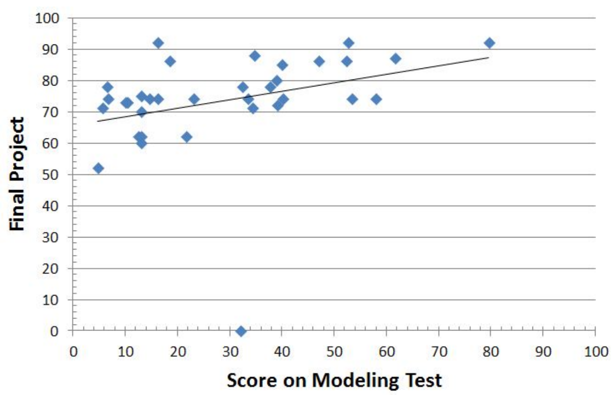

Figure 6. Modeling Test vs. Final Project.

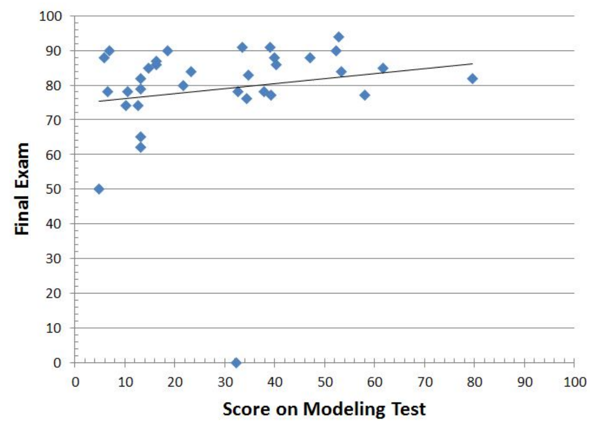

Figure 7. Modeling Test vs. Final Exam.

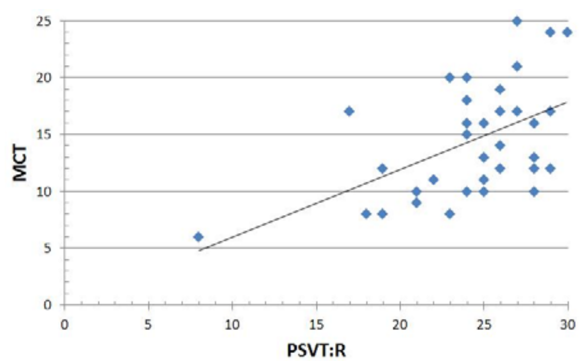

Figure 8. PSVT:R vs. MCT.

The scatterplots for the data display a relationship between the scores on the modeling test and the scores on the PSVT:R, MCT, final project, and final exam. The scatterplots also revealed some outliers in all of the data. Table 5 displays the descriptive statistics for students' scores on the modeling test, PSVT:R, MCT, final project, and final exam.

Table 5. Descriptive Statistics.

	N	Range	Min.	Max.	Mean		Std. Dev.	Variance
					Statistic	Std. Error		
PSVT:R	34	22.00	8.00	30.00	24.26	.75	4.39	19.23
MCT	34	19.00	6.00	25.00	14.44	.86	4.999	24.92
Modeling Test	34	74.82	4.80	79.62	29.09	3.26	19.03	362.04
Final Project	34	92.00	.00	92.00	73.62	2.77	16.14	260.55
Final Exam	34	94.00	.00	94.00	78.82	2.84	16.58	275.00

The data show that the modeling scores were very spread out with a large standard deviation. To get a better feel for the shape of the data for these variables, histograms are displayed in Figures 8-12.

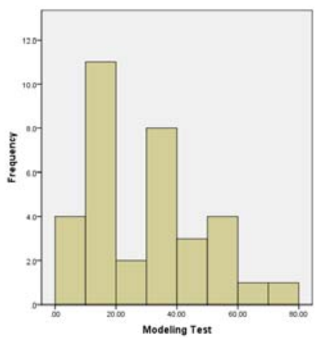

Figure 8. Modeling Test Histogram.

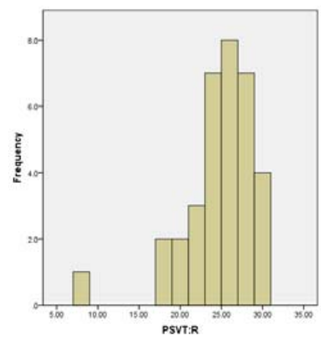

Figure 9. PSVT:R Histogram.

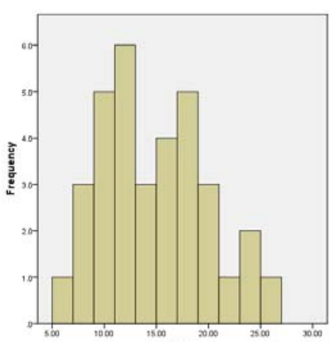

Figure 10. MCT Histogram.

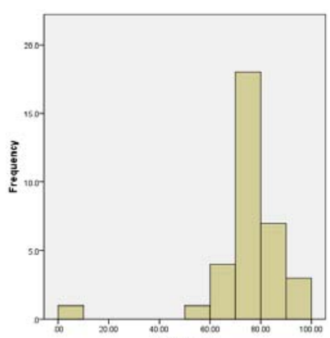

Figure 11. Project Histogram.

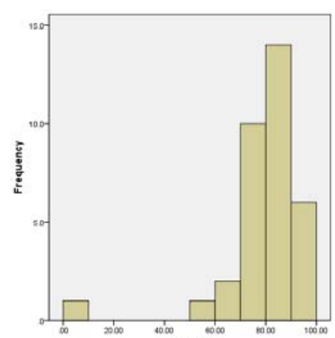

Figure 12. Exam Histogram.

The modeling test and MCT scores are spread out over the whole range of scores with a multi-node shape. Scores on the PSVT:R, final project and final exam appear to be skewed to one side with almost all scores in the top third of the range.

The main research question for this study was "is student's ability to interpret and model information from an assembly drawing related to their spatial visualization ability?" An additional research question was "how does this ability to read assembly drawings relate to other measures in the course (project and exam)?" Since the data do not meet assumptions for parametric tests, a non-parametric Spearman's Rho was used to test the hypotheses. Table 6 displays the data for these analyses.

Table 6. Spearman's Rho Correlations.

Spearman's rho		PSVT:R	MCT	Modeling Test	Final Project	Final Exam
PSVT:R	Correlation Coefficient	1.000				
	Sig. (2-tailed)	.				
	N	34				
MCT	Correlation Coefficient	**.490****	1.000			
	Sig. (2-tailed)	**.003**	.			
	N	34	34			
Model Test	Correlation Coefficient	**.499****	**.699****	1.000		
	Sig. (2-tailed)	**.003**	**.000**	.		
	N	34	34	34		
Final Project	Correlation Coefficient	.402*	.356*	**.540****	1.000	
	Sig. (2-tailed)	.018	.039	**.001**	.	
	N	34	34	34	34	
Final Exam	Correlation Coefficient	.358*	.195	.322	**.587****	1.000
	Sig. (2-tailed)	.037	.269	.063	**.000**	.
	N	34	34	34	34	34

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The Spearman's Rho analyses show significant correlations between scores on the modeling test and scores on the PSVT:R ($\rho = .499$, $\alpha = .003$), scores on the modeling test and scores on the MCT ($\rho = .699$, $\alpha = .000$), scores on the modeling test and scores on the final project ($\rho = .540$, $\alpha = .001$). As one might expect, there was also a significant correlation between the PSVT:R and the MCT ($\rho = .490$, $\alpha = .003$). The analyses did not reveal a significant correlation between the modeling test and the final exam.

Discussion

The analysis of the data revealed that there is a significant correlation between students' scores on the modeling test and three other measures in the study – PSVT:R, MCT and final project. There was not a strong correlation between students' scores on the modeling test and the final exam. This makes sense since the final exam includes much more “book” material from the course and does not require the students to visualize complicated geometry. The final project in the course is similar to the modeling test in that students are reading information in an engineering document (typically a pictorial representation of a part) and then modeling the parts. Although there are other elements to the project, the main component requires that students successfully visualize geometry and then model and assemble the parts.

After examining the scatterplots and descriptive statistics for the data, it is also evident that the only significant correlations with the modeling test were with the PSVT:R, MCT and the project. Scores on the final exam tended to fall at the top end of the range of scores and did not provide a strong trend. In other words, a high final exam score did not necessarily mean the student did well on the modeling test.

Conclusions

As with the previous studies, the main research question was whether a relationship exists between reading engineering drawings and spatial visualization ability. In this study students who scored higher on the PSVT:R and MCT tended to score higher on the modeling test. Although other factors influence how well students read engineering drawings, it appears that spatial visualization ability plays a key role it how well they visualize part geometry. It should be noted that for this study there was a stronger relationship between the modeling test and the MCT than the modeling test and the PSVT:R. The MCT requires students to imagine the cross sectional area of a part when given a cutting plane. This is similar to the strategy they must use when modeling parts. For the modeling tests students were required to visualize the 3D part from 2D drawings, determine the best plane on which to start, and then sketch appropriate geometry to extrude, revolve, cut, loft or sweep. The PSVT:R only requires students to mentally rotate objects. For these reasons the MCT might be a better choice for predicting success in 3D solid modeling than the PSVT:R.

For this study there was also a significant correlation between the students’ scores on the modeling test and the scores on the final project. Although not significant, there was a positive relationship between the final exam and the modeling test. It could be that spending more time on activities similar to the modeling test might improve performance on the final project and final exam.

Future Plans

This study revealed several interesting conclusions that deserve further investigation. These include, but are not limited to:

- Repeating the study to verify the results of the MCT data.
- Repeating the study at other institutions in the United States and Europe.
- Examining methods for automatically assessing the students’ models.
- Repeating the study with a shorter modeling activity.
- Use qualitative research methods to gain a deeper understanding of how students model parts from assembly drawing information.

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