# 3D Spatial Visualization Instruction within an Introductory Constraint-Based CAD Modeling Course

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**Abstract**

*Since the Fall 2010 semester, spatial visualization instruction has been integrated into the Introduction to Technical Drawing and Constraint-Based Modeling course at Illinois State University. In addition to these materials, the course also includes instruction in constraint-based CAD modeling and other engineering graphics topics. During the Fall 2015 semester, students were asked to complete the PSVT:R and the MCT to assess their spatial visualization abilities at the beginning of the course. These two assessments will also be given at the end of the course to determine the impact of the course activities on students' spatial visualization. This paper describes the activities in the course, gives demographic information on the students, presents descriptive statistics related to the pre-test scores, examines the relationship between the PSVT:R and the MCT, and compares the means on the PSVT:R and MCT between students who took the course as a requirement versus those who took it as an elective.*

**Introduction**

Educators have known and have written for more than 75 years about the importance that spatial visualization ability plays in developing successful engineers and technicians (Branoff, 2007; Clark & Scales, 2000; Howe, 1940; Meyers, 2000; Miller & Bertoline, 1991; Sorby, 1999; Sorby & Baartmans, 2000; Veurink & Sorby, 2012). One might assume that the nature of engineering design graphics activities exercises and strengthens spatial abilities, but students entering introductory courses with deficient skills in this area often get left behind others who have strong skills. Along with her colleagues, Sorby has developed curriculum materials to help improve the spatial visualization abilities of undergraduate engineering students who perform poorly on standardized measures (Sorby & Baartmans, 2000; Sorby, 2005). Research on these materials in a stand-alone intervention course has been well documented (Sorby, 2005; Sorby, 2006; Sorby, Drummer, Hungwe, Charlesworth, 2005; Veurink, et al., 2009). Students completing a course using the spatial visualization materials made significant gains in spatial visualization ability (Sorby, 2005; Veurink, et al, 2009), performed better in later engineering courses, and persisted in engineering at a higher rate than their peers who did not complete the spatial visualization course (Sorby, 2005). The materials have also been shown to improve spatial visualization abilities in non-engineering undergraduate students (Sorby, Drummer, Hungwe, Charlesworth, 2005) and middle school students (Sorby, 2006).

**Spatial Visualization Assessment**

Several instruments have been used to assess the spatial visualization abilities of students in engineering and technical graphics courses. Some of these include the Mental Rotations Test – MRT (Vandenberg & Kuse, 1978), the Purdue Spatial Visualization Test: Visualization of Rotations – PSVT:R (Guay, 1977), and the Mental Cutting Test – MCT (CEEB, 1939). Several studies indicate a significant correlation between the PSVT:R and the MCT (Branoff & Dobelis, 2013a, 2013b, 2014). These studies also indicate a significant correlation between these measures of spatial visualization and students' ability to create constraint-based solid models.

**Technical Drawing Course at Illinois State University**

Since the Fall semester of 2010, the spatial visualization materials from Sorby, Wysocki, and Baartmans (2003) have been integrated into the TEC 116 – Introduction to Technical Drawing and Constraint-Based Modeling course at Illinois State University. The course is designed to give students an overview of mechanical product design, including industry accepted technical drawing practices (orthographic projection theory, dimensioning, sectional views, threads and fasteners, and assembly drawings), constraint-based CAD practices, and basic print reading skills. Specific topics for the course focused on spatial visualization include isometric sketching, coded plans, rotations of objects, and Cartesian coordinate systems. Building upon the spatial visualization skills, the course introduces specific solid modeling skills such as fundamentals of modeling, sketching, extrusions, rotations, assemblies, and documenting models.

**Research Questions**

The current study was designed to conduct a preliminary investigation into the effectiveness of integrating spatial visualization materials into an existing introductory engineering graphics course. The research questions for this study were:

1. Is there a significant correlation between students' scores on the PSVT:R and the MCT?
2. Do students' taking an introductory engineering graphics course as a requirement perform differently on the PSVT:R and MCT than students taking the course as an elective?
3. Do students' scores on the PSVT:R and MCT increase significantly after completing an introductory engineering graphics course with integrated spatial visualization materials (NOTE: data will not be available to answer this research question until the end of the Fall 2015 semester)?

**Participants**

In the Fall 2015 semester, 56 students from two sections of TEC 116 at Illinois State University participated in the study. Tables 2-4 summarize the demographic information of the participants.

**Table 1. Gender of Participants.**

| Gender | Frequency | Percent |
|---|---|---|
| Female | 8 | 14.29% |
| Male | 48 | 85.71% |
| TOTAL | 56 | 100.00% |

**Table 2. Academic Year of Participants.**

| Year | Frequency | Percent |
|---|---|---|
| Freshman | 11 | 19.64% |
| Sophomore | 17 | 30.36% |
| Junior | 23 | 41.07% |
| Senior | 4 | 7.14% |
| Graduate Student | 1 | 1.79% |
| TOTAL | 56 | 100.00% |

**Table 3. Academic Major of Participants.**

| Major | Frequency | Percent |
|---|---|---|
| Computer Systems Technology | 10 | 17.86% |
| Engineering Technology | 19 | 33.93% |
| Graphic Communications | 12 | 21.43% |
| Renewable Energy | 3 | 5.36% |
| Technology & Engineering Education | 5 | 8.93% |
| Graduate Student | 1 | 1.79% |
| Other | 6 | 10.71% |
| TOTAL | 56 | 100.00% |

Most of the students in the course were male, with almost 75% of students enrolled in either computer systems technology, engineering technology, or graphics communications. The course is required for engineering technology, graphic communications, and technology & engineering education majors. Other students on campus take the course as an elective.

**Methodology & Results**

During the second class period of the semester, students were administered electronic versions of the PSVT:R and the MCT within the campus-wide learning management system. These assessments were selected based on previous research which showed strong correlations between the two assessments and correlations with 3D constraint-based modeling ability (Branoff & Dobelis, 2013a, 2013b, 2014). Each assessment was set up to terminate after 20 minutes. Table 4 displays the descriptive statistics for two assessments.

**Table 4. Descriptive Statistics.**

| Assessment Category | N | Min. | Max. | Mean | Std. Dev. |
|---|---|---|---|---|---|
| All participants – PSVT:R | 56 | 2 | 30 | 21.21 | 5.58 |
| Female participants – PSVT:R | 8 | 13 | 26 | 19.38 | 4.53 |
| Male participants – PSVT:R | 48 | 2 | 30 | 21.52 | 5.72 |
| Computer Systems Technology – PSVT:R | 10 | 2 | 24 | 16.80 | 6.89 |
| Engineering Technology – PSVT:R | 19 | 15 | 30 | 24.26 | 4.19 |
| Graphic Communications – PSVT:R | 12 | 10 | 27 | 20.50 | 5.55 |
| Renewable Energy – PSVT:R | 3 | 11 | 21 | 17.33 | 5.51 |
| Technology & Engineering Ed. – PSVT:R | 5 | 18 | 27 | 22.40 | 4.04 |
| Other majors – PSVT:R | 6 | 16 | 26 | 21.83 | 3.54 |
| All participants – MCT | 56 | 2 | 24 | 11.09 | 5.18 |
| Female participants – MCT | 8 | 3 | 15 | 9.75 | 3.96 |
| Male participants – MCT | 48 | 2 | 24 | 11.31 | 5.36 |
| Computer Systems Technology – MCT | 10 | 2 | 10 | 6.60 | 2.07 |
| Engineering Technology – MCT | 19 | 7 | 24 | 15.05 | 5.40 |
| Graphic Communications – MCT | 12 | 7 | 17 | 11.42 | 3.29 |
| Renewable Energy – MCT | 3 | 4 | 13 | 8.33 | 4.51 |
| Technology & Engineering Ed. – MCT | 5 | 6 | 12 | 9.60 | 2.61 |
| Other majors – MCT | 6 | 3 | 10 | 7.33 | 4.27 |

A scatterplot of the scores on the PSVT:R and the MCT was generated to determine whether a graphical relationship existed between scores on the two assessments (Figure 1). The scatterplot shows a positive relationship between the scores. Since the descriptive statistics indicate that some of the scores were spread out, histograms were created for the two assessments to determine if the data followed a normal distribution (Figures 2 & 3).

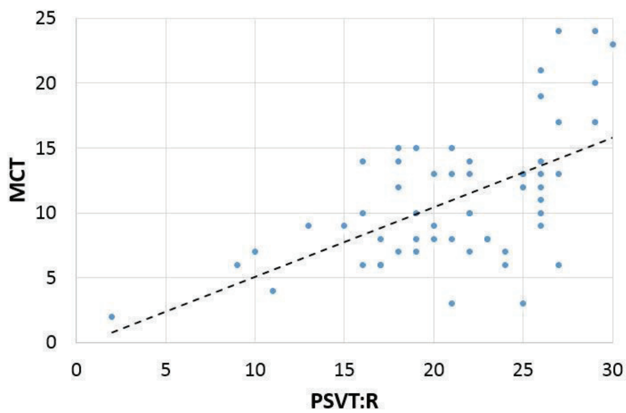


**Figure 1. PSVT:R vs. MCT.**

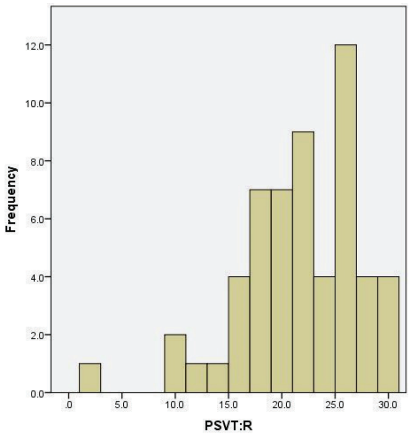


**Figure 2. PSVT:R Histogram.**

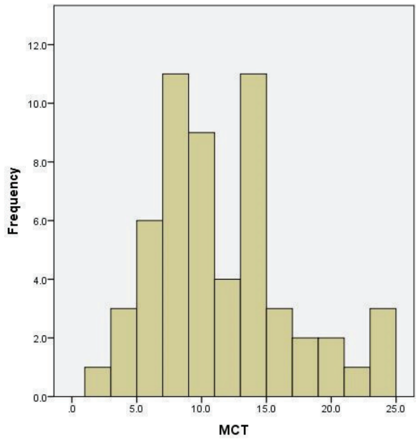


**Figure 3. MCT Histogram.**

Since the distributions of the data do not appear to be normal, a non-parametric Spearman's Rho test was used to determine if there was a correlation between the PSVT:R and the MCT. Table 5 displays the data for this analysis. The Spearman's Rho analysis revealed a significant correlation between the PSVT:R and the MCT ($\rho = .518$, $\alpha = .000$).

**Table 5. Spearman's Rho Correlations.**

| Spearman's rho | | PSVT:R | MCT |
|---|---|---|---|
| PSVT:R | Correlation Coefficient | 1.000 | |
| | Sig. (2-tailed) | . | |
| | N | 56 | |
| MCT | Correlation Coefficient | **.518*** | 1.000 |
| | Sig. (2-tailed) | **.000** | . |
| | N | 56 | 56 |

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

Students in engineering technology, graphic communications, and technology & engineering education take TEC 116 as a major requirement. All other students take the course as an elective. A Mann-Whitney U test was used to determine if there was a difference in scores on the PSVT:R and the MCT for students who took the course as a requirement versus those who took it as an elective. Table 6 displays the means for the two groups, and Table 7 shows the results of the analyses.

**Table 6. Means by Major Requirement.**

| Major Requirement | | PSVT:R | MCT |
|---|---|---|---|
| Elective | Mean | 18.474 | 7.105 |
| | N | 19 | 19 |
| | Std. Deviation | 6.0127 | 3.1428 |
| Required | Mean | 22.622 | 13.135 |
| | N | 37 | 37 |
| | Std. Deviation | 4.8497 | 4.8371 |
| Total | Mean | 21.214 | 11.089 |
| | N | 56 | 56 |
| | Std. Deviation | 5.5815 | 5.1814 |

**Table 7. Mann-Whitney U for Major Requirement.**

| | Major | N | Mean Rank | Sum of Ranks | Mann-Whitney U | Sig. (2-tailed) |
|---|---|---|---|---|---|---|
| PSVT:R | Elective | 19 | 20.55 | 390.50 | 200.50 | **.009 *** |
| | Required | 37 | 32.58 | 1205.50 | | |
| | Total | 56 | | | | |
| MCT | Elective | 19 | 15.00 | 285.00 | 95.00 | **.000 *** |
| | Required | 37 | 35.43 | 1311.00 | | |
| | Total | 56 | | | | |

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

The analyses revealed a significant difference in scores on the PSVT:R for students who were required to take TEC 116 and those who took the course as an elective. The same was true for the MCT. In both cases students who were required to take the course (engineering technology, graphic communications, and technology & engineering education) scored higher than students who were taking the course as an elective.

**Conclusions**

As has been shown in other studies where the PSVT:R and MCT have been given (Branoff & Dobelis, 2013a, 2013b, 2014), this study revealed a strong correlation between the two assessments. This is expected since the two tests purport to measure the same construct of spatial visualization ability.

The descriptive statistics connecting student major to performance on the PSVT:R and MCT show that students in the three majors that require TEC 116 scored consistently higher than students in majors which do not require the course. The Mann-Whitney U test confirmed that the difference is significant. Comparing the scores of students required to take the course shows that students majoring in engineering technology scored higher than all majors on both assessments. Graphic communications students scored higher on the MCT than technology & engineering education students, but the graphic communications students scored lower than the technology & engineering education students on the PSVT:R. It is unclear why the graphic communications students and technology & engineering education students were consistently different between the two assessments, especially when an overall strong correlation between the tests was observed.

**Future Work**

To determine the effectiveness of the spatial visualization materials on students' spatial visualization abilities, post-tests must be completed at the end of the semester. Future plans are to conduct these assessments during the last week of classes when all assignments have been completed.

To further explore the relationship between student major and spatial visualization abilities, research could be conducted on the factors that contribute to students required to take the course performing better on spatial visualization tests. Factors could include motivation, student interest in the topic, student background experiences related to spatial visualization, or other factors. Also, while there is a well-documented history of strong correlation between the PSVT:R and the MCT, this research shows that students in a specific major may not perform consistently between the two tests relative to other majors. Research could be conducted to discover if subtle differences in the two tests might assist students with different backgrounds to perform differently.

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