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The Role of Spatial Visualization Ability in Course Outcomes and Student Retention within Technology Programs

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Abstract. Some studies have shown that students who perform well on standard measures of spatial visualization ability progress at a higher rate in engineering programs than students who perform poorer on these measures. In addition, it has been shown that an independent spatial visualization course can improve performance on spatial visualization ability. TEC116, an introductory constraint-based modeling and engineering graphics course at Illinois State University, is required for Engineering Technology, Graphic Communications Technology, and Technology & Engineering Education majors. The course is also a technical elective for Computer Systems Technology and Sustainable & Renewable Energy majors. Exercises from Introduction to 3D Spatial Visualization: An Active Approach have been integrated into this course since the fall of 2010. The course also includes an introduction to part modeling, drawings, and assemblies using Autodesk Inventor. During the fall 2015 through the fall 2018 semesters, students were administered the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:R) and the Mental Cutting Test (MCT) as pre and post-test measures. This paper will report demographic data of the students enrolled in the course; spatial visualization scores; persistence data for the students enrolled in the course; spatial test outcomes by graduation status, mathematics grade, and grade in TEC116; and discuss future initiatives related to revising the curriculum.

Key Words: CAD, engineering graphics, spatial visualization

MSC 2020: 51N05 (primary), 51M04, 51N15

1 Introduction / Review of Literature

Engineering and technical graphics educators have been put much effort into studying and developing spatial visualization abilities in students [22, 23, 25, 26, 28, 35, 36]. This can be challenging since students enter universities with a wide range of spatial visualization abilities

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[11]. Activities that take place inside and outside of classrooms during students' early lives (e.g., playing with building blocks, participating in art activities, riding/repairing bicycles, sketching, woodworking, computer gaming, athletic activities, etc.) can have a great impact on their ability to mentally manipulate three-dimensional objects [11]. This has challenged educators to investigate the role spatial visualization plays in the development and success of engineers and technicians [2, 8, 16, 18, 19].

STEM fields have a profound influence on the nation's economic growth and prosperity. One area of concern for engineering/technology education is the development of students' spatial skills, particularly their ability to perform 3-D mental rotations. Research illustrates that well-developed spatial skills are linked to success in engineering and technology [21]. In fact, Wai, Lubinski, and Benbow [38] found that professionals in the STEM field often have better spatial skills than professionals in other disciplines, even after correlated abilities such as math and verbal skills are held constant. Spatial skills training has been shown to improve student performance on visualization tasks for both males and females [10, 24].

Well-developed spatial visualization skills are necessary for success in engineering and technology education programs [23]. The ability to imagine and visualize the transformation of spatial information is crucial for developing innovative engineering designs. Spatial skills are essential in engineering graphics to understand and create isometric and orthographic drawings, which are the tools used by engineers and technologists to communicate information about a component's exact shape and dimensions. Reaction time to mental rotation tasks has been shown to predict performance on an isometric and orthographic drawing assessment given at the end of a semester.

Studies have also addressed the difference between innate ability and spatial skills that may be enhanced through education. Although differences have been found on a mental rotation task in children as young as primary school age [13, 37], several factors have been attributed to the development of spatial skills, including prior experience playing with construction toys such as Legos, experience with sketching and drawing, and playing 3-D video games. Spatial visualization is also significantly different among gender who chose the technical and non-technical fields of study. This even is true depending on the international location, and the background experiences that they were involved.

Retention of students is a challenge in many universities. Students who are low in spatial skills are more likely to get frustrated and drop out of the engineering/technology programs due to difficulty understanding the spatially infused information that is inherent in early course work.

There are many standardized tests for assessing spatial visualization. The PSVT:R [14] has likely been the most commonly used instrument in engineering and technical graphics courses over the last 30 years [22, 23, 25–27, 35, 36]. Other frequently used assessments have been the MCT [9] and the Mental Rotations Test (MRT) [33]. The PSVT:R has been criticized for errors in the original test [40] and for challenges some students experience interpreting 3D solids from the isometric pictorial images used in the test [1].

1.1 STEM Student persistence

Many undergraduate STEM-focused programs have issues with student retention and persistence [32, 34]. Student persistence can be especially low for female and minority students [20] and first-generation college students [29]. Many factors inside and outside the classroom contribute to student retention and persistence. Historically, classroom student factors such as self-efficacy, academic success, and student engagement can be key factors [20], but there are clearly many other factors.

Outside the classroom, students encounter many issues that influence their persistence in higher education. Common factors that influence persistence include student demographics, pre-college academic experiences, and socioeconomic status [29]. Previous high school performance, institutional fit, and financial scholarships are important predictors for student persistence [12]. Also, the way that students pay for college can influence their overall performance and persistence [6]. Specific to first year engineering technology students, researchers identified seven factors directly connected to student persistence 1) Personal goals, 2) Classmate collaboration, 3) Faculty relationships, 4) Uneasy beginning, 5) Work effort, 6) Adaptability, and 7) Campus involvement [32].

Student preparation as a college STEM student can play a part in helping students persist with college. Students may not have begun higher education with a clear understanding of the role of a college student and/or how to behave to be a successful university student [7]. Instructors may need to provide different teaching methods and supports for students unprepared for higher education. Specifically, instead of providing implicit assumptions of behavior for college students, instructors may want to provide explicit instructions [7] and/or tutoring, mentoring, counseling services, early intervention systems, and financial aid assistance [6].

1.2 TEC 116 at Illinois State University

The introductory constraint-based modeling and engineering graphics course at Illinois State University includes introductory engineering graphics concepts (e.g., multiview and pictorial sketching, dimensioning, sectional views, etc.), constraint-based modeling concepts and exercises (e.g., Boolean operations, 2D sketch profiles, constraining sketches, modeling strategies, assembly modeling, etc.), and spatial visualization exercises. The spatial visualization activities from Introduction to 3D Spatial Visualization: An Active Approach [28] have been integrated into the course since 2010 to increase students' performance in 3D activities and improve persistence rates in departmental programs. The activities include creating coded plans to represent the heights of part features, sketching isometric pictorials of objects given a top view and the coded plan, sketching oblique pictorials given an isometric pictorial of the object and a line of sight, sketching isometric pictorials given an isometric pictorial and a rotation about an axis (90°, 180°, 270°) and rotations about two axes.

The course is required for students in Engineering Technology, Graphic Communications Technology, and Technology & Engineering Education. It is a technical elective for students in Computer Systems Technology & Sustainable and Renewable Energy. Approximately half of students admitted to the Engineering Technology program are external transfer students. Many of these students transfer in credit for TEC116.

1.3 Measures of Spatial Visualization Ability in TEC 116

Between Fall 2015 and Fall 2018, students were administered the PSVT:R and the MCT as pre and post-test measures in TEC116 to assess their spatial visualization abilities. The PSVT:R consists of 30 items of increasing level of difficulty. It is a 20-minute timed test. Initial items require a rotation of 90° on one axis followed by items requiring 180° rotation about one axis, rotation of 90° about two axes, and concluding with items requiring rotation of 90° about one axis and 180° about another axis. The first stimulus object used to specify the type of rotation is the same for all 30 items. The second stimulus object is different for each item. All objects are isometric pictorials of one of the following types of three-dimensional solids: truncated hexahedrons, right circular cylinders, right rectangular prisms, or right triangular prisms. Scoring the PSVT is simply a matter of adding the number of correctly answered items [15].

The MCT is a 20-minute timed test with 25 items. Each items includes a test solid with a plane indicating where the cut will take place. Students are required to select the correct cross-sectional area from 5 given images [9].

The assessments were administered electronically through the university's learning management system on the second and last days of the class. Each assessment was set up to terminate after 20 minutes per the original instructions. Errors in the original PSVT:R were corrected in the electronic version of the test [40].

2 Research Questions

The current study was designed to investigate the relationship between spatial visualization and several other variables for students enrolled in TEC116. Specific research questions were:

1. Did students who passed the post test spatial visualization tests graduate at a higher rate than those who failed the tests?
2. Did students who passed the post test spatial visualization tests persist in their major at a higher rate than those who failed the tests?
3. Did students who passed the post test spatial visualization tests pass TEC116 at a higher rate than those who failed the tests?

2.1 Participants

From Fall 2015 to Fall 2018, 321 students from over 25 different majors were enrolled in TEC116. Tables 1–5 summarize the demographic information on all students.

Table 1: Students Enrolled in TEC116 by Semester – Fall 2015-Fall 2018

Semester	**All Students**	
	N	**Percent**
Fall 2015	36	11.2%
Spring 2016	42	13.1%
Fall 2016	52	16.2%
Spring 2017	46	14.3%
Fall 2017	49	15.3%
Spring 2018	44	13.7%
Fall 2018	52	16.2%
TOTAL	**321**	**100.0%**

Table 2: Gender of Students in TEC116 – Fall 2015-Fall 2018.

Gender	**All Students**	
	N	Percent
Female	51	15.9%
Male	270	84.1%
TOTAL	**321**	**100.0%**

Table 3: Ethnicity of Students in TEC116.

Ethnicity	All Students	
	N	Percent
American Indian	2	60.0%
Asian	18	5.6%
Black/African American	48	15.0%
Hispanic	27	8.4%
White	226	70.4%
TOTAL	**321**	**100.0%**

Table 4: Academic Level of Students in TEC116.

Ethnicity	All Students	
	N	Percent
Freshmen	94	29.3%
Sophomore	93	29.0%
Junior	114	35.5%
Senior	19	5.9%
Graduate Student	1	30.0%
TOTAL	**321**	**100.0%**

Table 5: Academic Major of Students in TEC116

Major	N	Percent
Engineering Technology – *Required for major*	107	33.3%
Graphic Communications Technology – *Required for major*	51	15.9%
Computer Systems Technology – *Technical elective*	43	13.4%
Technology & Engineering Education – *Required for major*	43	13.4%
Undeclared	30	9.3%
Sustainable & Renewable Energy – *Technical elective*	18	5.6%
Information Technology (Computer Science, Cybersecurity, etc.)	8	2.5%
Sciences (Biology, Geography, Geology, Physics, etc.)	6	1.9%
Business (Accountancy, Business Administration, etc.)	5	1.6%
International Exchange	3	0.9%
Agriculture	1	0.3%
Construction Management	1	0.3%
Criminal Justice Sciences	1	0.3%
Fine Arts	1	0.3%
Occupational Health Safety	1	0.3%
Social Sciences (Communications, Mass Media, Sociology, etc.)	1	0.3%
Technology	1	0.3%
TOTAL	**321**	**100.0%**

Most of the students enrolled in TEC116 were white males, and approximately 30% were students of color. Engineering Technology students made up the largest percentage of enrolled students (33.3%). There were equal distributions of freshmen and sophomores enrolled, and juniors made up the largest percentage of enrollees (35.5%).

3 Methodology

The PSVT:R and MCT were selected as measures of spatial visualization ability since studies have indicated strong correlations between the two tests and with 3D constraint-based modeling ability [3–5]. The campus-wide learning management system was used to administer electronic versions of the PSVT:R and MCT to students enrolled in TEC116 during the regularly scheduled class periods on the second and last days of class each semester.

4 Results

Table 6 displays the PSVT:R and MCT data for all students. Using 60% as a passing score on each assessment (18/30 for the PSVT:R and 15/25 for the MCT), Table 7 shows the pass/fail results for the two assessments. Table 8 displays the breakdown of final grades in the course.

Table 6: Descriptive Statistics on Spatial Measures for TEC116 Students.

Assessment	N	Min.	Max.	Mean	Std. Dev.	Variance
PSVT:R Pretest	313	3	29	20.35	5.240	27.459
PSVT:R Posttest	297	5	30	21.83	5.628	31.674
MCT Pretest	314	0	24	10.49	4.470	19.982
MCT Posttest	295	1	24	12.09	4.597	21.128

Table 7: Pass/Fall Results for the PSVT:R and MCT Assessments.

Assessment	N	Percent
PSVT:R Prestest - Pass	222	70.9%
PSVT:R Prestest - Fail	91	29.1%
PSVT:R Pretest – TOTAL	**313**	**100.0%**
PSVT:R Posttest - Pass	227	76.4%
PSVT:R Posttest - Fail	70	23.6%
PSVT:R Posttest – TOTAL	**297**	**100.0%**
MCT Prestest - Pass	60	19.1%
MCT Prestest - Fail	254	80.9%
MCT Pretest – TOTAL	**314**	**100.0%**
MCT Posttest - Pass	89	30.2%
MCT Posttest - Fail	206	69.8%
MCT Posttest – TOTAL	**295**	**100.0%**

Table 8: Grade in TEC116

Grade	N	Percent
A	144	44.9%
B	117	36.4%
C	41	12.8%
D	9	2.8%
F	7	2.2%
WX	3	0.9%
TOTAL	**321**	**100.0%**

Of the 321 students enrolled in TEC116, 227 (76.4%) passed the PSVT:R pretest and 60 (19.1%) passed the MCT pretest. During the last week of classes, 227 (76.4%) passed the PSVT:R and 89 (30.2%) passed the MCT. A majority of the students passed both PSVT:R tests but failed the MCT tests. About 45% of the 321 students earned an "A" in the course, while less than 6% earned a "D", failed, or withdrew from the course.

Of primary interest to the researchers were the relationships of outcome on the spatial visualization tests to graduation status (graduated or still actively enrolled), outcome in mathematics (pass or fail), and outcome in TEC116 (pass or fail). To answer the research questions, two-by-two contingency tables/crosstabulations were conducted between the nominal variables of interest using the phi coefficient [39]. Posttest outcomes for the PSVT:R and MCT were used for these analyses. Table 9 shows the graduation status of all students who took TEC116 between the Fall 2015 and Fall 2018 semesters. Tables 10–15 display the results of these data for students who completed each of the spatial tests.

Table 9: Graduation Status of Students as of May 2022

Graduation Status	N	Percent
Graduated	265	82.6%
Still Active	10	3.1%
Dismissed	16	5.0%
Discontinued	30	9.3%
TOTAL	**321**	**100.0%**

Table 10: PSVT:R Posttest Outcome by Graduation Status

Measure		Graduated or Still Active				TOTAL	
		Yes	Percent	No	Percent	N	Percent
PSVT:R Posttest Outcome	**Pass**	201	88.5%	26	11.5%	227	100.0%
	Fail	61	87.1%	9	12.9%	70	100.0%
TOTAL		**262**	**88.2%**	**35**	**11.8%**	**297**	**100.0%**

Nominal by nominal measure	Value	Approximate Significance
Phi Coefficient	0.018	0.75

Table 11: MCT Posttest Outcome by Graduation Status

Measure		Graduated or Still Active				TOTAL	
		Yes	Percent	No	Percent	N	Percent
MCT Posttest Outcome	**Pass**	81	91.0%	8	9.0%	89	100.0%
	Fail	180	87.4%	26	12.6%	206	100.0%
TOTAL		**261**	**88.5%**	**34**	**11.5%**	**295**	**100.0%**

Nominal by nominal measure	Value	Approximate Significance
Phi Coefficient	0.052	0.370

Table 12: PSVT:R Posttest Outcome by Mathematics Outcome.

Measure		Mathematics Outcome				TOTAL	
		Pass	Percent	Fail	Percent	N	Percent
PSVT:R Posttest Outcome	**Pass**	197	90.0%	22	10.0%	219	100.0%
	Fail	59	90.8%	6	10.2%	65	100.0%
TOTAL		**256**	**90.1%**	**28**	**9.9%**	**284**	**100.0%**

Nominal by nominal measure	Value	Approximate Significance
Phi Coefficient	-0.011	0.847

Table 13: MCT Posttest Outcome by Mathematics Outcome

Measure		Mathematics Outcome				TOTAL	
		Pass	Percent	Fail	Percent	N	Percent
MCT Posttest Outcome	**Pass**	77	91.7%	7	8.3%	84	100.0%
	Fail	177	89.4%	21	10.6%	198	100.0%
TOTAL		**254**	**90.1%**	**28**	**9.9%**	**282**	**100.0%**

Nominal by nominal measure	Value	Approximate Significance
Phi Coefficient	0.035	0.559

Table 14: PSVT:R Posttest Outcome by TEC116 Outcome

Measure		TEC 116 Outcome				TOTAL	
		Pass	Percent	Fail	Percent	N	Percent
PSVT:R Posttest Outcome	**Pass**	224	98.7%	3	11.3%	227	100.0%
	Fail	65	92.9%	5	7.1%	70	100.0%
TOTAL		**289**	**97.3%**	**8**	**2.7%**	**297**	**100.0%**

Nominal by nominal measure	Value	Approximate Significance
Phi Coefficient	0.153	0.009
	* Significant at the 0.05 level	

Table 15: MCT Posttest Outcome by TEC116 Outcome

Measure		TEC 116 Outcome				TOTAL	
		Pass	Percent	Fail	Percent	N	Percent
MCT Posttest Outcome	**Pass**	88	98.9%	1	1.1%	89	100.0%
	Fail	201	97.6%	5	2.4%	206	100.0%
TOTAL		**289**	**98.0%**	**6**	**2.0%**	**295**	**100.0%**

Nominal by nominal measure	Value	Approximate Significance
Phi Coefficient	0.042	0.467

There were no significant associations between the spatial test outcomes and graduation status and mathematics course outcome. There was also no association between the MCT posttest outcome and the TEC116 course outcome. There was a positive association between the PSVT:R posttest outcome and the TEC116 course outcome. Students who completed and passed the PSVT:R posttest tended to pass the TEC116 course.

5 Conclusions

Two hundred and seventy-five of the original 321 students in this study persisted at the university (85.7%). Two hundred sixty-five students graduated, and 10 were still taking coursework toward their degree. There did not appear to be a relationship between spatial visualization ability and graduation status. When examining students who graduated or were still active at the university, 61 of 262 students failed the PSVT:R posttest (23%) and 180 of 261 failed the MCT posttest (69%). Although research indicates spatial visualization plays a key role in the success of students, results from this study indicate overall success must include other factors. Because of the varied major degree programs taking the TEC 116 course, we cannot be certain of the number of courses related to spatial visualization and/or graphics taken by each individual student. Technology graduates enter a wide range of fields that draw on a variety of skill sets. Many students who struggle with spatial visualization ability may flourish in areas such as project management, technical sales, or quality assurance.

The data in this study also did not reveal an association between spatial visualization ability and outcome in the mathematics course (pass or fail). When examining students who passed their mathematics course at the university or transferred in a passing mathematics course, 59 of 256 students failed the PSVT:R posttest (23%) and 177 of 254 failed the MCT posttest (70%). Although there have been studies that have shown positive associations between spatial ability and mathematics achievement, not all types of mathematical abilities have the same types of relationships with spatial visualization ability. Numerical and arithmetical ability appear to have less association with spatial ability than logical reasoning [39].

The data in this study did show a positive correlation between spatial visualization ability (as measured by the PSVT:R) and TEC116 course outcome. Of the 289 students who passed TEC116 with a grade of "C" or higher, 224 students (78%) passed the PSVT:R posttest. This result was not consistent with spatial visualization as measured by the MCT. Only 88 of the 289 students (30%) passed both the MCT posttest and the TEC116 course. Although previous research has indicated a positive correlation between the MCT and constraint-based modeling ability [3, 4, 17] and the MCT and those taking a descriptive geometry course [30, 31], success in TEC116 included mastering other content such as engineering graphics standards, dimensioning practices, and multiview sketching.

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