ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #37088

Student Retention in an Engineering Technology Program: The Role of Spatial Visualization Ability

Theodore J. Branoff (Chair-Department of Technology)

Dr. Branoff is a professor and chair of the Department of Technology at Illinois State University. He taught engineering graphics, computer-aided design, descriptive geometry, and instructional design courses in the College of Education at North Carolina State University from 1986-2014, and he teaches a geometric dimensioning and tolerancing course at Illinois State University. Dr. Branoff's research interests include constraint-based solid modeling strategies, spatial visualization abilities in undergraduate students, and best practices in GD&T instruction. He has conducted CAD and GD&T workshops for both industry and education professionals. Dr. Branoff has served in several roles within the Engineering Design Graphics Division of ASEE including Director of Programs, Chair, Vice-Chair, Associate Editor of the Engineering Design Graphics Journal, and Director of Professional & Technical Committees. In 2013, he was elected into the Academy of Fellows of the American Society for Engineering Education, and in 2014 he received the Distinguished Service Award from the Engineering Design Graphics Division of ASEE.

Jaby Mohammed (Assistant Professor)

Jaby Mohammed is an Assistant Professor of Technology at Illinois State University, where he teaches Data Analytics, Six Sigma, and Parametric modeling. After working with Khalifa University, Purdue University, and Morehead State University, Dr. Mohammed joined the technology department at Illinois State University. He worked as engineering faculty with Kentucky Governors Scholars Program from 2006-to 2012. Dr. Mohammed is a senior member of the Society of Manufacturing Engineers (SME) and the Institute of Industrial Engineers (IIE). His area of research includes New Product development, human factors, six sigma, and Lean Manufacturing. He has conducted applied research in laser cladding and rapid prototyping using DMD and SLS machines. Dr. Mohammed holds a Ph.D. in Industrial Engineering from the University of Louisville, an MBA in operations management, and his Bachelor’s in mechanical engineering from University of Kerala.

Student Retention in an Engineering Technology Program: The Role of Spatial Visualization Ability

Abstract

Research has shown that students who perform poorly on standard measures of spatial visualization ability do not progress as well in engineering programs as students who perform better on these measures [1, 2]. Studies have shown that spatial visualization performance can be improved through an independent spatial visualization course [1-4]. Students in the Engineering Technology program at Illinois State University are required to take TEC116, an introductory constraint-based modeling and engineering graphics course. Exercises from *Introduction to 3D Spatial Visualization: An Active Approach* [5] 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) [6] and the Mental Cutting Test (MCT) [7] 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 Engineering Technology majors enrolled in the course, outcomes in other major courses, graduation data, and discuss future initiatives related to revising the Engineering Technology curriculum.

Introduction / Review of Literature

Over the last thirty years, engineering and technical graphics educators have dedicated more time to studying and developing spatial visualization abilities in students [1-3, 5, 8-10]. Challenges have occurred since students enter universities with a wide range of spatial visualization abilities [11]. Academic and non-academic activities during students' early years (e.g., playing with building blocks, participating in art activities, riding/repairing bicycles, sketching, woodworking, computer gaming, athletic activities, etc.) have an impact on their ability to mentally manipulate three-dimensional objects [11], which has led educators to investigate the role spatial visualization plays in the development and success of engineers and technicians [12-16].

There are many standardized tests for assessing spatial visualization. The PSVT:R [6] has likely been the most commonly used instrument in engineering and technical graphics courses over the last 30 years [1-4, 8-10]. Other frequently used assessments have been the MCT [7] and the Mental Rotations Test (MRT) [17]. The PSVT:R has been criticized for errors in the original test [18] and for challenges some students experience interpreting 3D solids from the isometric pictorial images used in the test [19].

TEC116 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* [5] have been integrated into the course since 2010 to increase students' performance in 3D activities and improve persistence rates in departmental programs. 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 and Sustainable & 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.

Between Fall 2015 and Fall 2018, students were administered the PSVT:R and the MRT as pre and post-test measures in TEC116 to assess their spatial visualization abilities. 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 [18].

Research Questions

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

1. What were the outcomes related to spatial visualization performance and grade in the course?
2. What were the outcomes related to spatial visualization performance and performance in other key Engineering Technology core courses?
3. What were the outcomes related to spatial visualization performance and persistence in Engineering Technology?
4. What were the outcomes related to spatial visualization performance and graduation rates for Engineering Technology students?

Participants

From Fall 2015 to Fall 2018, 326 students from over 25 different majors were enrolled in TEC116. Tables 1-5 summarize the demographic information on all students. The far-right columns display data for Engineering Technology students.

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

Semester	All Students		Engineering Technology Students	
	N	Percent	N	Percent
Fall 2015	37	11.3%	13	12.1%
Spring 2016	42	12.9%	15	14.0%
Fall 2016	52	16.0%	27	25.2%
Spring 2017	47	14.4%	15	14.0%
Fall 2017	52	16.0%	11	10.3%
Spring 2018	44	13.5%	13	12.1%
Fall 2018	52	16.0%	13	12.1%
TOTAL	**326**	**100.0%**	**107**	**100.0%**

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

Gender	All Students		Engineering Technology Students	
	N	Percent	N	Percent
Female	52	16.0%	7	6.5%
Male	274	84.0%	100	93.5%
TOTAL	**326**	**100.0%**	**107**	**100.0%**

Table 3. Ethnicity of Students in TEC116.

Ethnicity	All Students		Engineering Technology Students	
	N	Percent	N	Percent
American Indian	2	0.6%	0	0.0%
Asian	20	6.1%	3	2.8%
Black	48	14.7%	21	19.6%
Hispanic	27	8.3%	8	7.5%
White	229	70.2%	75	70.1%
TOTAL	**326**	**100.0%**	**107**	**100.0%**

Table 4. Academic Level of Students in TEC116.

Academic Level	All Students		Engineering Technology Students	
	N	Percent	N	Percent
Freshmen	96	29.4%	33	30.8%
Sophomore	94	28.8%	30	28.0%
Junior	115	35.3%	36	33.6%
Senior	20	6.1%	8	7.5%
Graduate Student	1	0.3%	0	0.0%
TOTAL	**326**	**100.0%**	**107**	**100.0%**

Table 5. Academic Major of Students in TEC116.

Academic Level	N	Percent
Engineering Technology – *Required for major*	107	32.8%
Graphic Communications Technology – *Required for major*	53	16.3%
Computer Systems Technology – *Technical elective*	44	13.5%
Technology & Engineering Education – *Required for major*	43	13.2%
Undeclared	31	9.5%
Sustainable & Renewable Energy – *Technical elective*	19	5.8%
Information Technology (Computer Science, Cybersecurity, etc.)	8	2.5%
Sciences (Biology, Geography, Geology, Physics, etc.)	6	1.8%
Business (Accountancy, Business Administration, etc.)	5	1.5%
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	**326**	**100.0%**

Most of the students enrolled in TEC116 were white males. About 6.5% of the Engineering Technology majors were female, and approximately 30% were students of color. Engineering Technology students made up the largest percentage of enrolled students (32.8%), and there were fairly equal distributions of freshmen, sophomores, and juniors enrolled.

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 [20-22]. During the regularly scheduled class periods on the second and last days of class each semester, the campus-wide learning management system was used to administer electronic versions of the PSVT:R and MCT to students enrolled in TEC116.

Results

Table 6 displays the PSVT:R and MCT data for Engineering Technology 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 for Engineering Technology students.

Table 6. Descriptive Statistics of Engineering Technology Students in TEC116.

Assessment	N	Min.	Max.	Mean	Std. Dev.	Variance
PSVT:R Pretest	107	7	29	20.44	4.981	24.815
PSVT:R Posttest	102	5	30	21.36	5.908	34.907
MCT Pretest	107	1	24	10.23	4.279	18.313
MCT Posttest	102	2	24	12.14	4.556	20.753

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

Assessment	N	Percent
PSVT:R Pretest – Pass	75	70.1%
PSVT:R Pretest – Fail	32	29.9%
PSVT:R Pretest – TOTAL	107	100.0%
PSVT:R Posttest – Pass	75	73.5%
PSVT:R Posttest – Fall	27	26.5%
PSVT:R Posttest – TOTAL	102	100.0%
MCT Pretest – Pass	18	16.8%
MCT Pretest – Fail	89	83.2%
MCT Pretest – TOTAL	107	100.0%
MCT Posttest – Pass	30	29.4%
MCT Posttest – Fail	72	70.6%
MCT Posttest - TOTAL	102	100.0%

Table 8. Grade in TEC116.

Grade	N	Percent
A	54	50.5%
B	40	37.4%
C	10	9.3%
D	2	1.9%
F	1	.9%
TOTAL	**107**	**100.0%**

Of the 107 Engineering Technology students enrolled in TEC116, 75 (70.1%) passed the PSVT:R pretest and 18 (16.8%) passed the MCT pretest. During the last week of classes, 102 Engineering Technology students completed the posttest assessments. Seventy-five (73.5%) passed the PSVT:R and 30 (29.4%) passed the MCT. A majority of the students passed both PSVT:R tests but failed the MCT tests. About half of the 107 students earned an "A" in the course, while less than 3% earned a "D" or failed.

Also of interest to the researchers was how performance on the spatial visualization assessments compared with performance in other courses in the Engineering Technology curriculum. Figures 1-7 display the results of the PSVT:R and MCT posttests by final grades in TEC116, MAT120 (Finite Mathematics), PHY105 (Fundamentals of Physics, TEC216 (Constraint-Based Solid Modeling & Production Drawings), TEC233 (CNC and Machining), TEC234 (Robotics Systems Integration), and TEC392 (Capstone: Manufacturing Organization & Management). Since all data in this study was compiled during the Fall 2021 semester, some students may not have completed all their coursework (no grade reported).

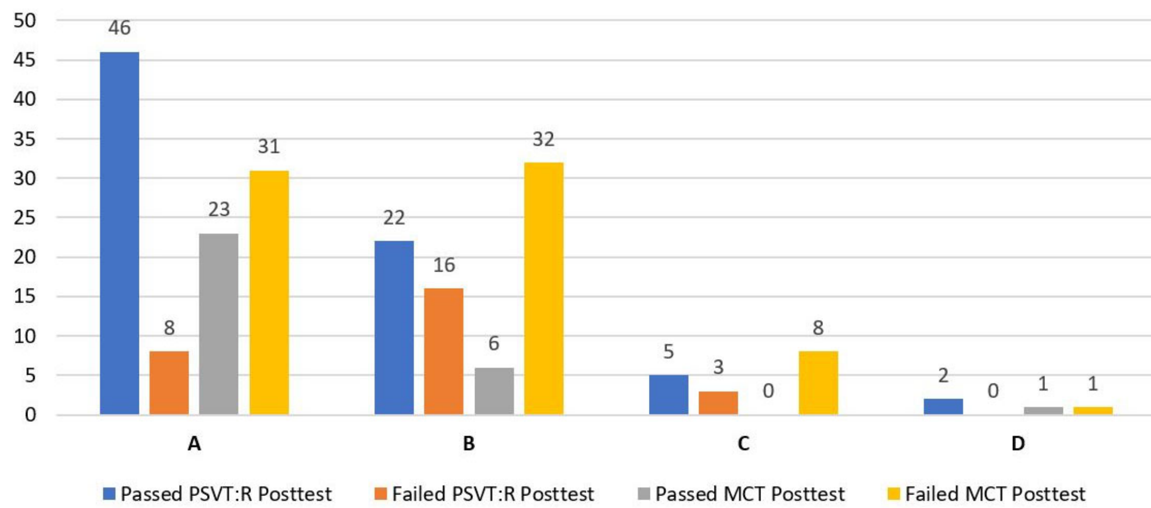

Figure 1. Grade in TEC116 by Posttest Outcomes.

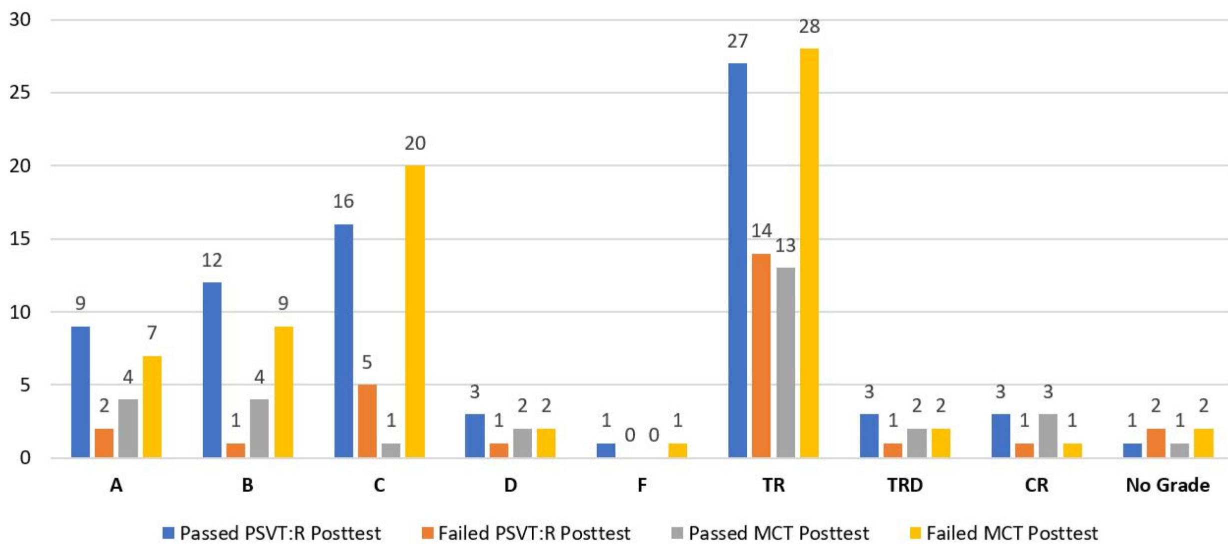

Figure 2. Grade in MAT120 (Finite Mathematics) by Posttest Outcomes.

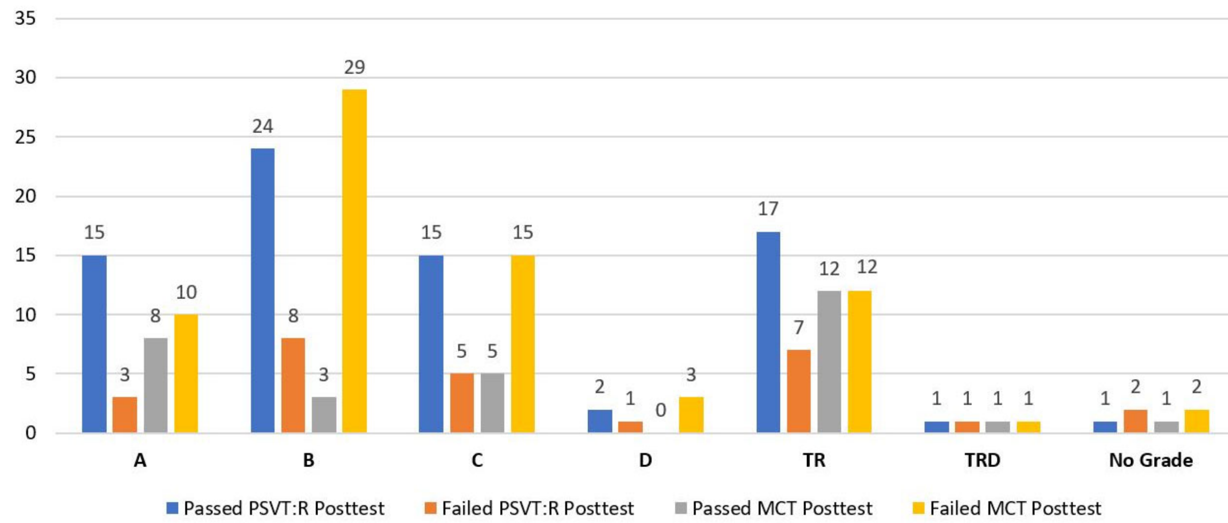

Figure 3. Grade in PHY105 (Physics) by Posttest Outcomes.

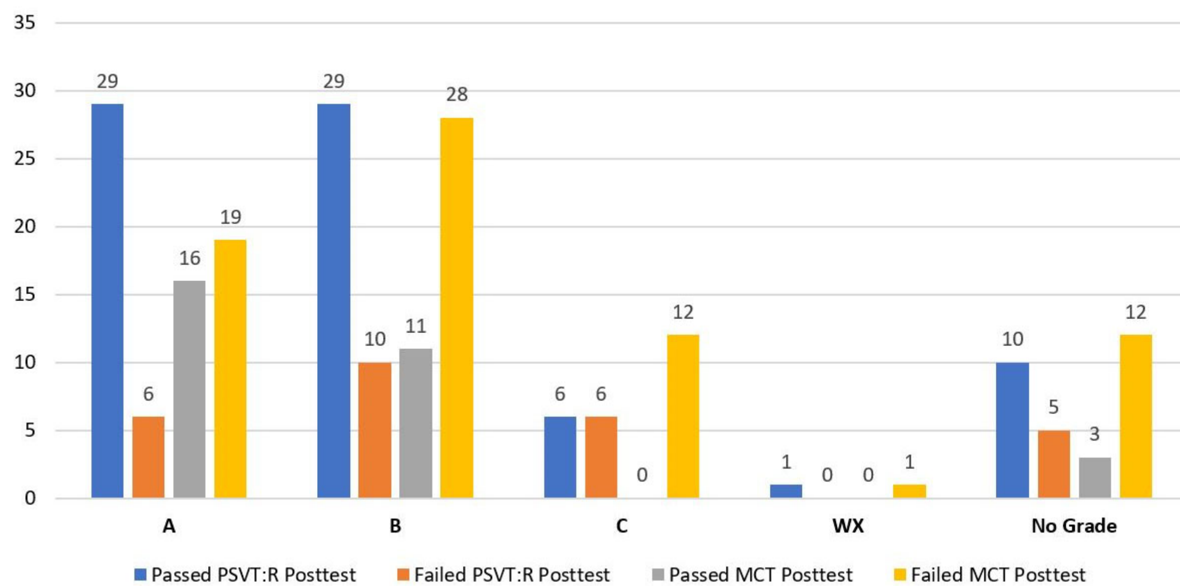

Figure 4. Grade in TEC216 (Constraint-Based CAD & Prod Dwgs) by Posttest Outcomes.

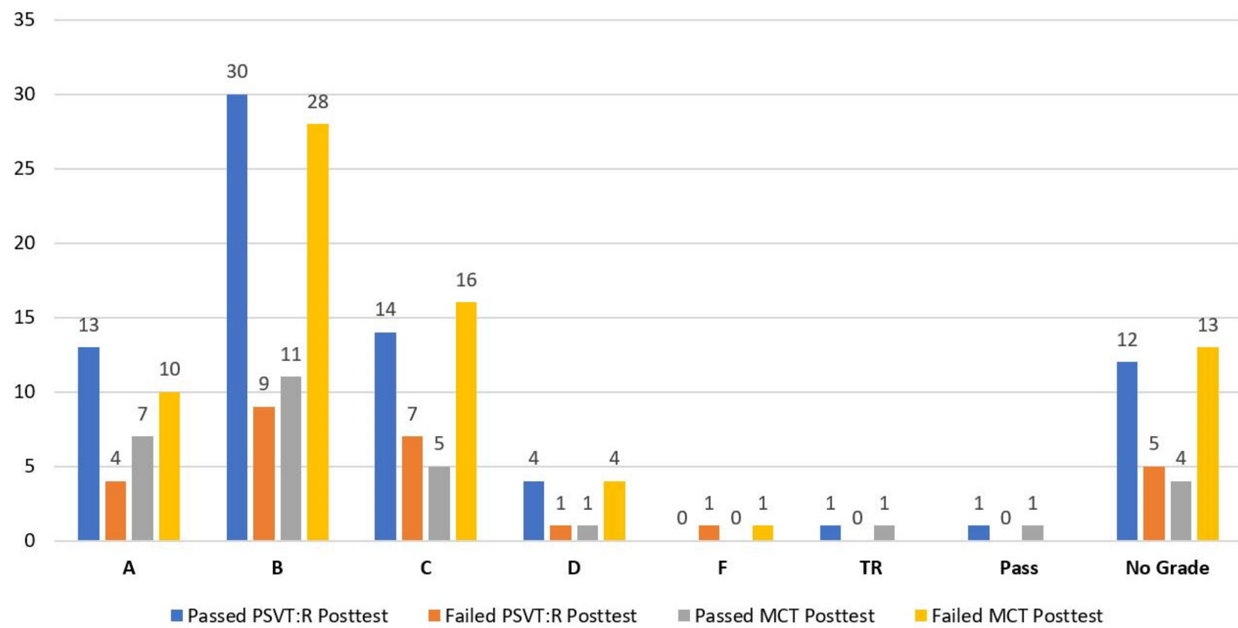

Figure 5. Grade in TEC233 (CNC & Machining) by Posttest Outcomes.

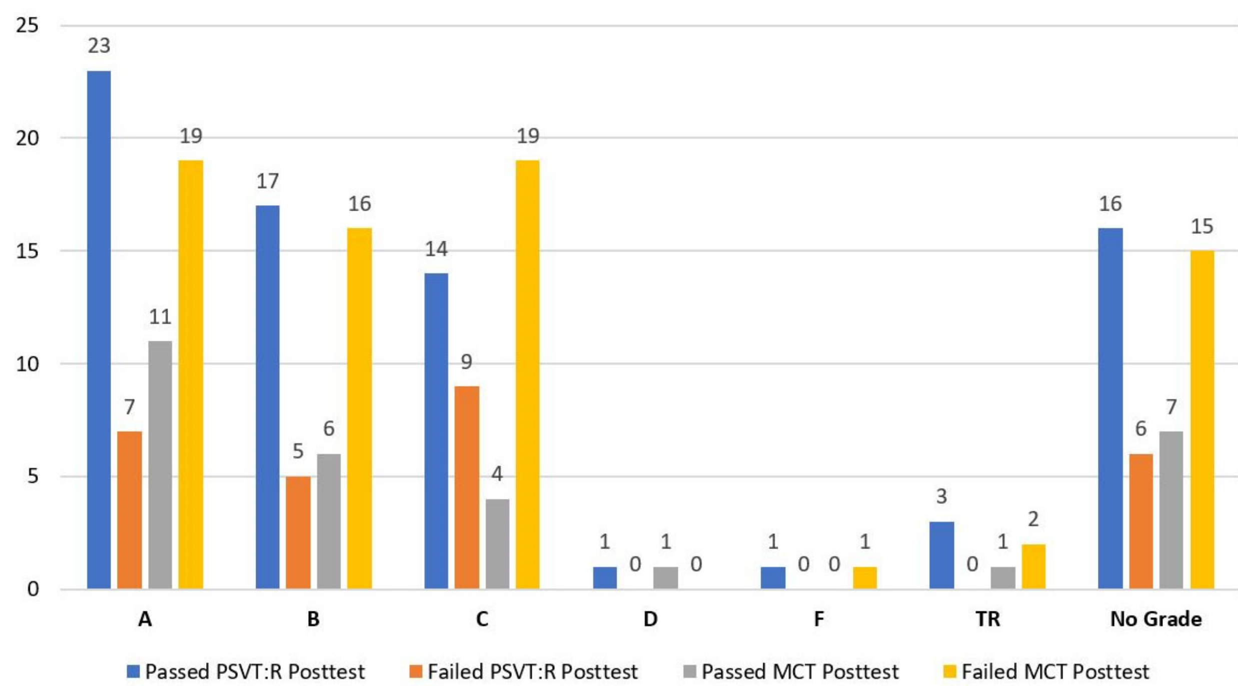

Figure 6. Grade in TEC234 (Robotics) by Posttest Outcomes.

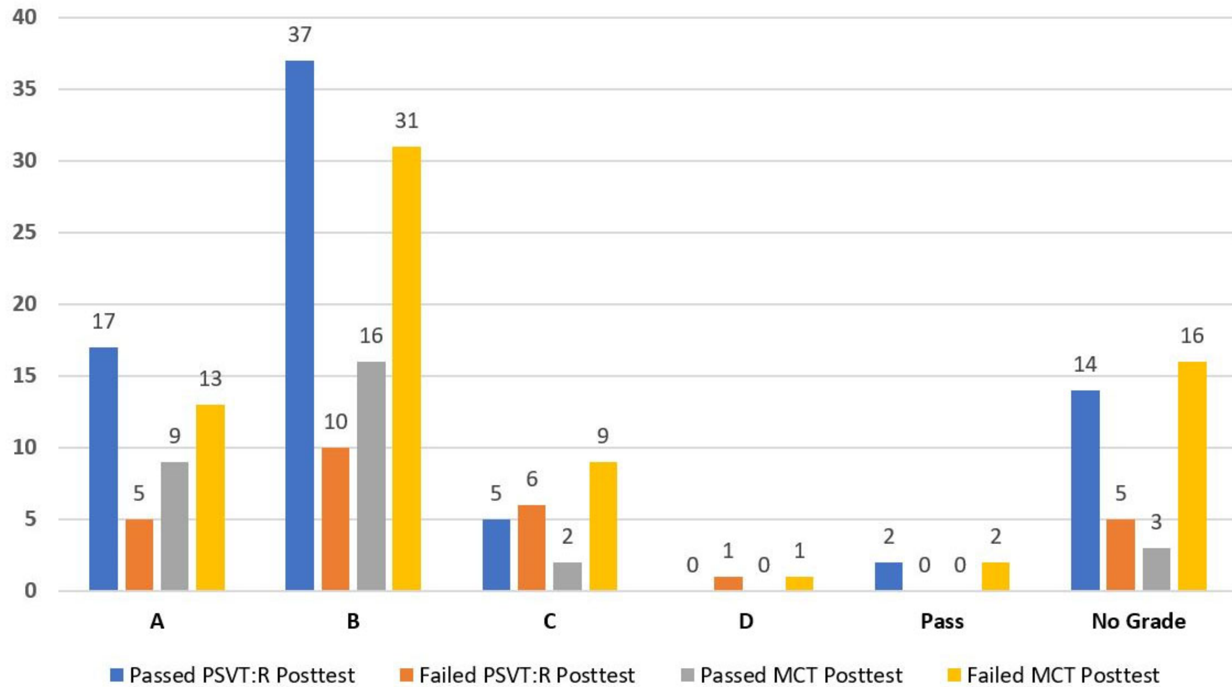

Figure 7. Grade in TEC392 (Capstone) by Posttest Outcomes.

Although Figures 1-7 may reveal more about overall grade distributions in these courses than relationships between spatial visualization and performance in the course, there are a few items worth noting. First, about half of the students in Engineering Technology are external transfer students. Figures 2 and 3 show that many students transferred the required mathematics and physics courses from a previous institution.

The data in this study show that fewer students passed the MCT posttest than passed the PSVT:R posttest. However, for students who completed TEC116, TEC216, TEC234, and passed the MCT, at least 50% earned an "A" in those courses.

Table 9 displays the overall graduation status of the 107 Engineering Technology students in the study. Table 10 breaks this down further based on the outcome of the PSVT:R and the MCT. Table 11 shows the graduation status of the participants based on their current major (students still active in their program) and final major.

Table 9. Graduation Status Engineering Technology Students during Fall 2021.

Academic Level	N	Percent
Graduated	93	86.9%
Active	4	3.7%
Dismissed	4	3.7%
Discontinued	6	5.6%
TOTAL	**107**	**100.0%**

Table 10. Graduation Status by Outcome on Posttests.

Assessment & Result	Graduated	Active	Dismissed	Discontinued	TOTAL
Passed PSVT:R Posttest	67	2	3	3	75
Failed PSVT:R Posttest	23	1	0	3	27
TOTAL	**90**	**3**	**3**	**6**	**102**
Passed MCT Posttest	29	0	0	1	30
Failed MCT Posttest	61	3	3	5	72
TOTAL	**90**	**3**	**3**	**6**	**102**

Table 11. Current/Final Major of Students.

Academic Major	Graduated	Active	Dismissed	Discontinued	N	Percent
Engineering Technology	85	4	2	4	95	88.8%
Undeclared	0	0	2	1	3	2.8%
Sustainable & Renewable Energy	2	0	0	0	2	1.9%
Information Technology (Computer Science, Cybersecurity, etc.)	2	0	0	0	2	1.9%
Business (Accountancy, Business Administration, etc.)	1	0	0	0	1	0.9%
Sciences (Biology, Geography, Geology, Physics, etc.)	1	0	0	0	1	0.9%
Construction Management	1	0	0	0	1	0.9%
Criminal Justice Sciences	1	0	0	0	1	0.9%
University Studies	0	0	0	1	1	0.9%
TOTAL	**93**	**4**	**4**	**6**	**107**	**100.0%**

Of the 107 students who were registered as Engineering Technology students during TEC116, 97 either graduated (93) or were still active in their current program of study in the Fall of 2021 (4). Four students were dismissed, and 6 discontinued their studies. Outcomes on the spatial visualization tests do not appear to have any bearing on graduation status (Table 10). Of the initial 107 Engineering Technology majors, twelve students changed to a different major after taking TEC116.

Conclusions

Eighty-nine of the initial 107 Engineering Technology students in this study persisted in the Engineering Technology program (83%). Eighty-five students graduated, and 4 were still active in the program. Ninety-seven of the 107 students persisted at the university (91%). There did not appear to be a relationship between spatial visualization ability and persistence within Engineering Technology. When examining students who graduated or were still active in the Engineering Technology program, 24 of 90 students failed the PSVT:R posttest (27%) and 62 of

90 failed the MCT posttest (69%). Although we can assume spatial visualization plays a key role in the success of students, data in this study indicate overall success includes other factors. Engineering Technology graduates enter a wide range of fields that include robotics systems integration, plastics technology, and technical sales. Many students who struggle with spatial visualization ability may flourish in other areas such as project management or programmable logic control.

The data regarding outcomes in other courses within the Engineering Technology curriculum showed mixed results. Figures 1-7 display grade distributions by outcomes of the PSVT:R and MCT posttests. In general, there appears to be no relationship between passing these spatial visualization tests and grades in courses. At least half of the students who passed the MCT posttest and persisted in the Engineering Technology program earned an "A" in TEC116, TEC216, and TEC234. Much of the time spent in TEC116 and TEC216 involves 3D constraint-based modeling, and TEC234 requires students to work with multiple datum reference frames simultaneously. These findings are consistent with previous research, which indicates the MCT has a high correlation with constraint-based modeling ability [20-22].

Future Research

This initial study has brought up several questions that require future study. For the 107 Engineering Technology students in this study, mean pretest scores on the PSVT:R and MCT were 20.44 and 10.23, respectively. These means were approximately 1 to 4 points lower than results at engineering universities [4, 10, 20] but much higher than engineering and technology students at an east coast HBCU [23]. Future work might involve examining relationships between spatial visualization scores and other data (e.g., standardized test scores, data from underrepresented groups, etc.) to inform faculty about retention and student success initiatives. In addition, future studies could examine persistence data on all students who took TEC116 between the Fall 2015 and Fall 2018 semesters. Engineering Technology students were less than 33% of all students enrolled in TEC116 during this period, and persistence data on other majors would provide useful information for other programs within the department.

References

1. Sorby, S. A. (2005). Assessment of a" new and improved" course for the development of 3-D spatial skills. *The Engineering Design Graphics Journal*, *69*(3).
2. Veurink, N. L., Hamlin, A. J., Kampe, J. C. M., Sorby, S. A., Blasko, D. G., Holliday-Darr, K. A., Trich Kremer, J. D., Abe Harris, L. V., Connolly, P. E., Sadowski, M. A., Harris, K. S., Brus, C. P., Boyle, L. N., Study, N. E., & Knott, T. W. (2009). Enhancing visualization skills-improving options and success (EnVİSIONS) of engineering and technology students. *The Engineering Design Graphics Journal*, *73*(2).
3. Rafaelli, L., Sorby, S. A., & Hungwe, K. (2006). Developing 3D spatial skills for K-12 students. *The Engineering Design Graphics Journal*, *70*(3).
4. Sorby, S. A., Drummer, T., Hungwe, K., Charlesworth, P. (2005). Developing 3-D spatial visualization skills for non-engineering students. *Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition*, 10.428.1-10.428.11.
5. Sorby, S. A., Wysocki, A. F., & Baartmans, B. G. (2003). *Introduction to 3D Spatial Visualization: an active approach*. Cengage Learning.

6. Guay, R. (1977). Purdue Spatial Visualization Test – Visualization of Rotations. W. Lafayette, IN. Purdue Research Foundation.
7. College Entrance Examination Board. (1939). *Special aptitude test in spatial relations*. CEEB.
8. Sorby, S. A. (1999). Developing 3-D spatial visualization skills, *Engineering Design Graphics Journal, 63* (2), 21-32.
9. Sorby, S. A., & Baartmans, B. J. (2000). The development and assessment of a course for enhancing the 3-D spatial visualization skills of first year engineering students, *Journal of Engineering Education, 89* (3), 301-307.
10. Veurink, N. L., & Sorby, S. A. (2012). Comparison of spatial skills of students entering different engineering majors, *Journal of Engineering Education, 76* (3), 49-54.
11. Deno, J. A. (1995). The relationship of previous experiences to spatial visualization ability, *Engineering Design Graphics Journal, 59* (3), 5-17.
12. Branoff, T. J. (2007). The state of engineering design graphics in the United States, *Proceedings of the 40th Anniversary Conference of the Japan Society for Graphic Science,* Tokyo, Japan, May 12-13, 2007, 1-8.
13. Clark, A. C., & Scales, A. Y. (2000). A study of current trends and issues related to technical/engineering design graphics, *Engineering Design Graphics Journal, 64* (1), 24-34.
14. Howe, H. B. (1940). Aims of a modern course in applied descriptive geometry, *Journal of Engineering Drawing, 4* (2), 2-3.
15. Meyers, F. D. (2000). First year engineering graphics curricula in major engineering colleges, *Engineering Design Graphics Journal, 64* (2), 23-28.
16. Miller, C. L., & Bertoline, G. R. (1991). Spatial visualization research and theories: Their importance in the development of an engineering and technical design graphics curriculum model, *Engineering Design Graphics Journal, 55* (3), 5-14.
17. Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations: A group test of three-dimensional spatial visualization, *Perceptual and Motor Skills, 47*, 599-604.
18. Yue, J. (2008). Spatial visualization by realistic 3D views. *Engineering Design Graphics Journal, 72*(1), 28-38.
19. Branoff, T. J. (2000). Spatial visualization measurement: A modification of the Purdue Spatial Visualization Test-Visualization of Rotations. *Engineering Design Graphics Journal, 64*(2), 14-22.
20. Branoff, T. J., & Dobelis, M. (June, 2013). The relationship between students' ability to model objects from assembly drawing information and spatial visualization ability as measured by the PSVT:R and MCT. *Proceedings of the 2013 Annual Meeting of the American Society for Engineering Education, Atlanta, Georgia, June 23-26, 2013.*
21. Branoff, T. J., & Dobelis, M. (October, 2013). Spatial visualization ability and students' ability to model objects from engineering assembly drawings. *Paper published in the proceedings of the 68th Midyear Conference of the Engineering Design Graphics Division of the American Society for Engineering Education, Worcester, Massachusetts, November 20-22, 2013.*
22. Branoff, T. J., & Dobelis, M. (June, 2014). Relationship between students' spatial visualization ability and the ability to create 3D constraint-based models from various types of drawings. *Proceedings of the 2014 Annual Meeting of the American Society for Engineering Education, Indianapolis, Indiana, June 15-18, 2014.*
23. Study, N. (June, 2006). Using remediation to improve spatial visualization abilities in minority engineering and technology students. *Proceedings of the 2006 Annual Meeting of the American Society for Engineering Education, Chicago, Illinois, June 18-21, 2006.*