



Examining the Interaction of Spatial Visualization Ability and Computer-aided Design and Manufacturing Course Performance

Dr. Michael Johnson, Texas A&M University

Dr. Michael D. Johnson is an associate professor in the Department of Engineering Technology and Industrial Distribution at Texas A&M University. Prior to joining the faculty at Texas A&M, he was a senior product development engineer at the 3M Corporate Research Laboratory in St. Paul, Minnesota. He received his B.S. in mechanical engineering from Michigan State University and his S.M. and Ph.D. from the Massachusetts Institute of Technology. Dr. Johnson's research focuses on design tools; specifically, the cost modeling and analysis of product development and manufacturing systems; computer-aided design methodology; and engineering education.

Dr. So Yoon Yoon, Texas A&M University

So Yoon Yoon, Ph.D., is a post-doctoral research associate at Texas A&M University. She received her Ph.D. and M.S.Ed. in Educational Psychology with the specialties in Gifted Education and Research Methods & Measurement, respectively from Purdue University. Her work centers on P-16 engineering education research, as a psychometrician, program evaluator, and institutional data analyst. As a psychometrician, she revised the PSVT:R for secondary and undergraduate students, developed the TESS (Teaching Engineering Self-efficacy Scale) for K-12 teachers, and rescaled the SASI (Student Attitudinal Success Inventory) for engineering students. As a program evaluator, she has evaluated the effects of teacher professional development (TPD) programs on K-6 teachers' and elementary students' attitudes toward engineering and STEM knowledge. As an institutional data analyst, she is investigating engineering students' pathways to their success, exploring subgroup variations.

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Abstract

Computer-aided design and manufacturing (CAD/CAM) tools are ubiquitous in the modern product commercialization environment. Students entering this environment will need to be well skilled in using these tools. One of the key skills associated with both CAD and CAM is spatial visualization. While several studies have examined the relationship between CAD and spatial visualization ability, there has been significantly less work investigating visualization ability's relationship with CAM. A better understanding of the relationship between spatial visualization ability and CAD/CAM course performance as well as the effects of these courses on student visualization ability (through pre- and post-tests) could enhance student performance with these essential tools.

This work uses the Revised Purdue Spatial Visualization Tests: Visualization of Rotations (Revised PSVT:R) to assess undergraduate students' spatial visualization ability. The participants of this study are students who have taken a CAM or CAD course at a large southwestern public university. Students' pre- and post-course spatial visualization data from the two courses are compared. In addition, spatial visualization test scores are compared to laboratory exercise performance metrics and other demographic data.

Results show that on average, students achieved relatively high scores on the Revised PSVT:R compared to the average scores of first year engineering students in the literature. A positive correlation between the Revised PSVT:R score and performance in both the CAD course and the CAM course are shown. Neither CAD courses nor CAM courses are seen to increase student spatial visualization ability. As students taking those courses are already juniors or seniors who took similar courses before, their high scores on the Revised PSVT:R implies that their spatial ability could already be saturated, meaning little or no room for improvement.

Introduction

In the modern world of product development and commercialization, computer-aided tools of various types are used in the engineering process. These CAx tools include computer-aided design (CAD), computer-aided manufacturing (CAM) and computer-aided engineering (CAE) analysis tools; these tools are ubiquitous in the modern engineering environment¹. As companies move towards the model based enterprise (MBE), the ability to fluidly use these tools will become more important². In the MBE, the model is at the core of improving development process efficiency. Spatial visualization is a critical skill for interacting and engaging in these CAx tools. Over two decades ago, Norman³ noted the importance of spatial visualization ability in computer-based technology.

Mohler's⁴ comprehensive review of spatial visualization research shows that for the vast majority of the history of the field, spatial visualization was examined through its psychometric relationship to intelligence. Some of these studies have examined the differences between the sexes as well as how spatial ability develops⁴. Kinsey *et al.*⁵, examine the effect of spatial

visualization ability on student retention in engineering and the physical sciences; they find that students who remained in those fields scored statistically significantly higher on visualization tests. Veurink and Sorby⁶ find that students who entered more spatially demanding majors had higher spatial visualization ability.

Given the importance of this skill, ways of examining how to improve spatial visualization ability have been documented. An extensive meta-analysis by Uttal *et al.*⁷ shows the significant effect that an intervention, through even a small amount of training, can have across sexes and ages. Sorby and Baartmans⁸ show that when placed in a graphics course to improve their spatial visualization skills, students that had originally scored poorly on a spatial ability test increase their spatial visualization ability, perform better in graphics related courses, and are retained at higher rates in engineering. A more recent version of that course using more multimedia and less instructor time had similar results in improving spatial visualization ability⁹. Martín-Gutiérrez *et al.*¹⁰ use a remedial course that incorporates augmented reality to significantly improve the spatial ability of students. Professional experience has also been shown to improve spatial ability.¹¹

A variety of tools are proposed to evaluate the spatial visualization ability of target populations. Martín-Gutiérrez *et al.*¹⁰ and⁸ use the Mental Rotation Test (MRT)¹² and the Differential Aptitude test (DAT-5: SR)¹³. The MRT, as named, examines the participant's ability to mentally rotate an object; the DAT-5: SR asks respondents to visualize a folded two-dimensional pattern. Another commonly used^{8, 14, 15} test is the Mental Cutting Test (MCT)¹⁶ assesses participants' ability to determine the shape of a section cut from a presented isometric view of an object. Specific tests used in the apparel industry include the Paper Folding Test and the Apparel Spatial Visualization Test¹¹. One of the most widely used^{5, 6, 8, 9} spatial visualization ability assessment instruments is the Purdue Spatial Visualization Test: Rotations (PSVT:R)¹⁷. The PSVT:R has been updated to incorporate realistic 3D views¹⁸. Some have criticized the PSVT:R for using isometric views which can be "confusing" and for lacking hidden lines¹⁹. A Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R)^{20, 21} has also been developed and assessed as a reliable and valid instrument to assess spatial visualization ability of college students^{21, 22}. The Revised PSVT:R is used in this work to assess spatial visualization ability.

In addition to examining general academic performance and retention, spatial visualization ability has also been related to CAD and graphics course performance. Leopold *et al.*¹⁴ examine the relationship between pre-course spatial visualization assessments and performance in introductory graphics courses at universities in the US, Poland, and Germany. They find that that pre-course MCT and DAT:SR scores are significantly positively correlated with final exam performance; in the case of the MRT, it is not significantly correlated at the US university, but is significantly positively correlated at the other two universities. Adanez and Velasco¹⁵ find that students that scored poorly in an introductory technical drawing course had significantly lower MCT scores than those that performed acceptable or well. Branoff and Dobelis²³ find a correlation between PSVT:R test scores and scores on a modeling test that consists of translating a 2D assembly drawing into 3D assembly CAD model.

While extensive work has been done examining the relationships between spatial visualization ability and persistence in STEM or between spatial ability and performance in introductory graphics courses, little work has been done to examine the effects of spatial ability on more senior students. Most previous work also focuses on translating between 2D drawings and 3D CAD models or between 3D items and 2D drawings. Very little work examines the ability of students to properly translate 3D objects into 3D CAD models which is a common task in modern parametric modeling. Finally, little has been done outside of CAD, which given the role that the broader set of CAx tools have in the modern development environment is a significant oversight. Students entering today's engineering design profession will need to be capable of using the various CAx tools necessary to facilitate virtual design and development. This work attempts to overcome these current shortcomings in the literature by examining a group of junior-level (3rd year) students in both a parametric CAD course and a computer-aided manufacturing (CAM) course.

Methods

To assess the spatial visualization ability of a more senior group of students, two courses in the Manufacturing and Mechanical Engineering Technology program at Texas A&M University, College Station. The first course is a product design course where students are taught about the product commercialization process in the lecture portion of the course. In the lab portion, students learn about 3D parametric modeling through a combination of guided and self-paced exercises. PTC's Creo Parametric is used during the laboratory portion of this course (ENTC 361); this course is denoted – CAD Course. The other is a computer-aided manufacturing course (ENTC 380). In the lecture portion of the course, students evaluate and analyze production systems, learn about automation technologies, and material handling technologies. In the laboratory portion of the course students learn the computer-aided manufacturing program FeatureCAM. In the laboratory portion of the course students are guided through the process for creating numerical code for the machining of various components; this course is denoted – CAM Course. There is also a project that entails students creating the required numerical code for the manufacture of an artifact of their choosing of moderate complexity.

As mentioned previously, the Revised Purdue Spatial Visualization Test: Visualization of Rotations (Revised PSVT:R)²⁰ is used to assess spatial ability in this work. The Revised PSVT:R is a multiple choice test that consists of 30 questions that ask respondents to evaluate how one set of rotations is related to another set of rotations. An example question from the Revised PSVT:R is shown in Figure 1. The Revised PSVT:R was administered during the lecture portion of both courses in both a Pre-test and a Post-test condition. The Pre-test was administered during the 3rd week of classes prior to a significant portion of material being covered in the laboratories (which typically start the second week of classes). The Post-test was administered during the penultimate week of regularly scheduled classes; during this time regular laboratory meetings are concluded. In both the Pre-test and the Post-test conditions, students were told they did not have a time limit to complete the assessment.

In addition to the Revised PSVT:R (and consent), demographic data were also collected (i.e., age and gender). These data included check boxes asking for students to identify which other popular CAD or CAM courses they had taken during their curriculum; blank space was left to allow for courses not on the list to be specified. Students were also asked to identify if they had ever taken

a spatial visualization test, their gender, and their age. They were also asked about their professional and technical experience, namely have you had an internship or co-op and have you ever worked in a laboratory or machine shop. A copy of the demographic survey is shown in the Appendix. To assess the relationship between spatial ability and CAD/CAM related course material lab practical grades were used in the CAD Course and overall lab grade was used in the CAM Course.

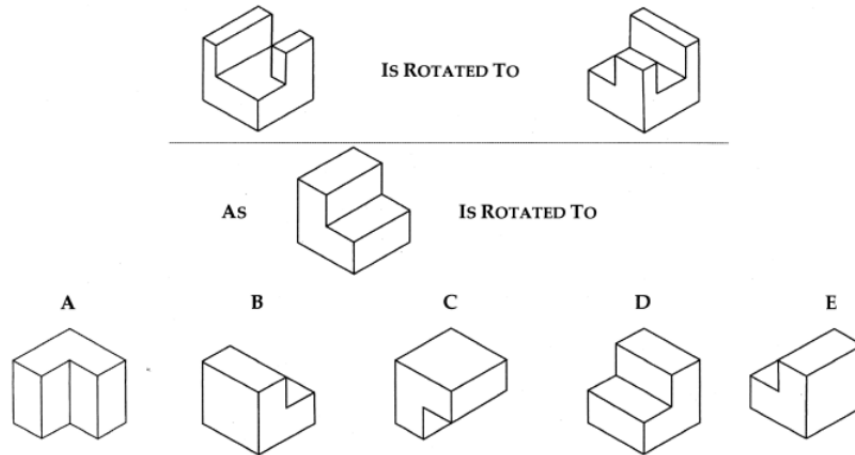


Figure 1. Sample Question from the Revised PSVT:R

CAD Course Laboratory Practicals

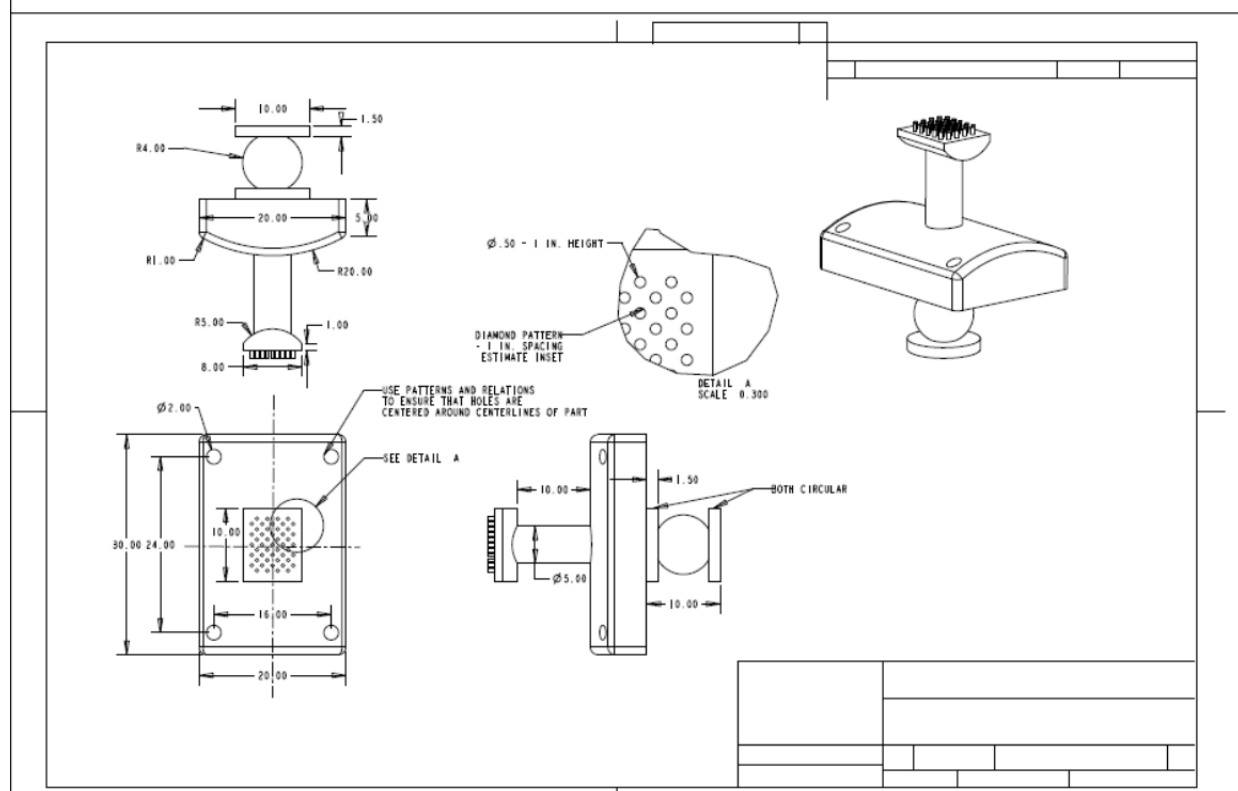


Figure 2. Drawing Distributed to Students for Lab Practical in Semester 1.

In Semester 1, the laboratory practical consisted of students being given a drawing of a component and asked them to create a CAD model of that component. The practical requires students to use the various skills demonstrated in the course to date. The drawing provided to the students for the laboratory practical is shown in Figure 2. The laboratory practical is graded on a 20 point scale based on the various major pieces of geometry (extrusions and revolve features), the creation patterns, and the connection of the features. The laboratory practical is administered after all of the initial geometry creation exercises in the course, but prior to students learning about drawings and assemblies. This laboratory practical experience is typical of the type of the CAD course skill used to evaluate the relationship between spatial ability and CAD skill (e.g., Branoff and Dobelis²³).

To assess the ability of students to model a 3D component in 3D CAD, during Semester 2 an alternative laboratory practical was used. In this case, students were given the markers shown in Figure 3 and told to model them in CAD. Again, these laboratory practicals were graded on a 20 point scale. Students were told that they had to model the taper of the marker body, the cap indentions and overall shape, as well as the necessary rounds and chamfers. Students were also required to relate the size of the cap to the size of the octagon at the end of the marker body (similar to the relation required in the original laboratory practical).



Figure 3. Photo (a.) and CAD Model (b.) of Marker Used for Lab Practical in Semester 2.

CAM Course Laboratory Exercises

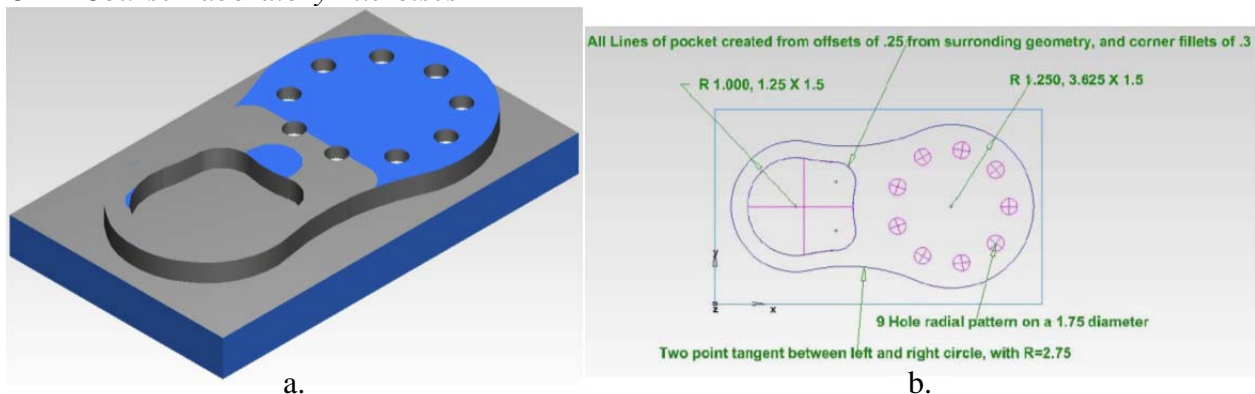


Figure 4. CAM Course Laboratory Exercise Requiring the Generation of Complex Curves Showing the Expected Geometry (a.) and Necessary Machining Requirements (b.).

The relationship between spatial ability and CAM skills uses the overall laboratory grade for the CAM Course. During the CAM Course, students are given a grade of 50 points for each

laboratory exercise: 25 points for participation; 20 points for a laboratory report which contains the necessary NC-code, an explanation of process steps, and a discussion of lessons learned and recommendations; and 5 points for laboratory quizzes. Exercises typically require students to create the NC-code required to create an artifact using computer numerically controlled machining centers. This requires students to create the component in the FeatureCAM program as well as the associated process plan. The process plan requires the student to identify which tools are necessary to machine the component. Two examples are shown in Figures 4 and 5. Overall lab grades for the CAM Course are reported as out of 100 possible points.

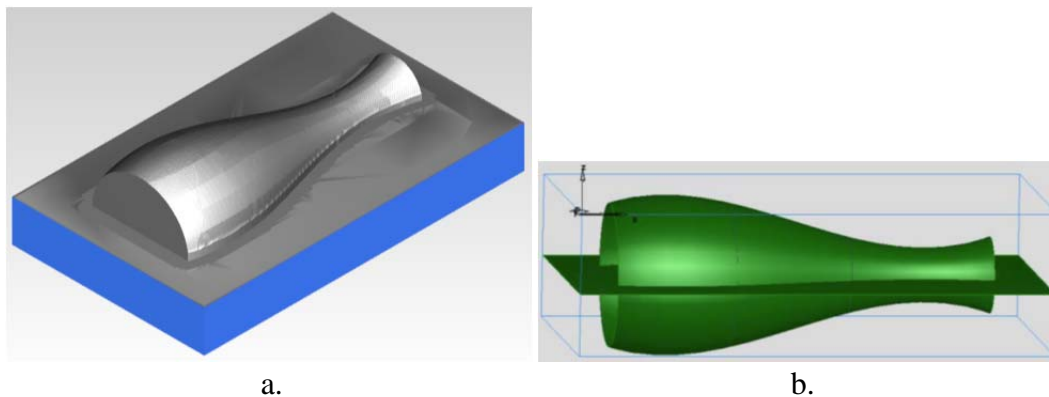


Figure 5. CAM Course Laboratory Exercise Requiring the Generation of Complex Curves Showing the Expected Geometry (a.) and Necessary Lofted Surfaces (b.).

This work assesses the following research questions with respect to the effects of CAD/CAM course and other professional experiences on spatial visualization ability:

- *R1*: What effect does prior professional experience have on spatial visualization ability?
 - *R1a*: Are previous engineering experience correlated with spatial visualization ability?
 - *R1b*: Are previous non-engineering technical correlated with spatial visualization ability?
- *R2*: What effect do CAD/CAM course experiences have on spatial visualization ability?
 - *R2a*: Does an intermediate CAD course have an effect on spatial visualization ability?
 - *R2b*: Does a CAM course have an effect on spatial visualization ability?
 - *R2c*: Does accumulated CAD/CAM course experience have an effect on spatial visualization ability?
- *R3*: Is spatial visualization ability correlated with CAD/CAM course performance?
 - *R3a*: Is spatial visualization ability correlated with CAM course performance?
 - *R3b*: Is spatial visualization ability correlated with students' ability to model 2D drawings in 3D CAD?
 - *R3c*: Is spatial visualization ability correlated with students' ability to translate 3D artifacts into 3D CAD?

To compare mean differences between two groups, independent *t*-test statistics were applied for outcomes of students between CAD and CAM courses, and dependent *t*-test statistics were applied for pre- and post-score comparisons on the spatial test. All assumptions for *t*-tests were checked prior to the analyses and correlation coefficients among the variables of interest were calculated.

Results

Table 1. Summary Data for Both Courses over Semesters 1 and 2

		CAD Course			CAM Course			<i>t</i>	<i>p</i>
		<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>		
Sem1	Age	40	21.5	1.2	40	21.6	3.6	0.041	0.967
	Number of CAD/CAM Courses	45	2.3	0.8	45	1.8	0.8	3.128	0.002
	Grade	45	12.4	5.0	44	81.9	8.3	N/A	N/A
	Pre-test	41	26.1	3.5	44	24.2	4.2	2.269	0.026
	Post-test	44	25.2	4.4	42	23.0	5.5	2.100	0.039
Sem2	Age	39	22.7	5.3	37	22.5	4.9	0.200	0.842
	Number of CAD/CAM Courses	47	2.5	1.0	43	1.8	0.9	3.309	0.001
	Grade	46	11.9	4.0	42	84.3	8.3	N/A	N/A
	Pre-test	43	24.3	3.8	38	23.7	4.5	0.694	0.490
	Post-test	45	24.7	4.0	39	24.5	4.0	0.281	0.780

In Semester 1, 36 students were administered the Revised PSVT:R in the CAD Course; 36 students were administered the test in the CAM Course; and 9 students were enrolled in both courses (in these cases students only took the assessment once). In Semester 2, 40 students were administered the Revised PSVT:R in the CAD Course; 36 students were administered the test in the CAM Course; and 7 students were enrolled in both courses. Summary data is shown in Tables 1 and 2. It should be noted that not all participants took both the Pre-test and the Post-test and not all participants responded to all of the demographic questions. In cases where students were concurrently enrolled in both courses, their data are included in both summaries. Demographic data with respect to gender is not reported due to the small *n*, thereby making these results identifiable.

Table 2. Comparison of Data between Semesters 1 and 2

	CAD Course		CAM Course	
	<i>t</i>	<i>p</i>	<i>t</i>	<i>p</i>
Age	1.339	0.185	0.917	0.362
Number of CAD/CAM Courses	0.942	0.349	0.189	0.851
Grade	0.442	0.660	1.386	0.169
Pre-test	2.209	0.030	0.517	0.606
Post-test	0.528	0.599	1.504	0.137

In Tables 1 and 2 (and all subsequent tables) statistically significant ($\alpha=0.050$; all *p* values two-tailed) differences are bolded. There was a significant difference in the number of CAD/CAM related courses taken between those participants in the CAD Course and those in the CAM Course; this was true in both semesters and is likely a result a significant number of students taking the CAM Course prior to the CAD Course; this would add to the total for the CAD Course. In Semester 1, both the Pre-test and the Post-test scores were higher in the CAD Course than the CAM Course. Comparisons of the data between the two semesters are shown in Table 2. The only significant difference is the higher Pre-test score in Semester 1 for the CAD Course. There were no significant differences in the grades for the two semesters. The lack of significant differences between the two semesters supports the assumption to consider the individual course data (i.e., the combined CAM course data) as uniform in nature.

Table 3. Comparison of Pre-test Scores Based on Previous Experience

	Yes			No			<i>t</i>	<i>p</i>
	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>		
Previous Visualization Test	34	24.8	3.6	110	24.1	4.3	0.854	0.395
Previous Professional Experience	42	23.9	4.6	100	24.4	4.0	-0.584	0.560
Previous Technical Experience	63	24.0	4.3	81	24.5	4.0	-0.702	0.484
	1			> 1				
Number of CAD/CAM Courses	45	23.4	4.6	107	24.9	3.9	1.9522	0.0528

Table 4. Comparison of Pre-test and Post-test Scores by Course

	<i>N</i>	Pre-test			Post-test		<i>t</i>	<i>p</i>
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>			
CAD Course	68	25.2	3.7	25.1	4.0	0.265	0.791	
CAM Course	62	23.7	4.4	23.3	5.1	0.839	0.405	
Co-enrolled in CAD and CAM	13	25.9	3.5	26.4	3.3	-1.389	0.190	
Overall Group	143	24.6	4.0	24.4	4.6	0.675	0.501	

To examine the role of previous experience (research question *R1*), Pre-test scores were compared for those with certain previous experiences. Having taken a visualization test did not significantly impact the score on the Pre-test. Previous practical engineering and technical experiences also did not affect the score on the Pre-test. These negative responses to *R1a* and *R1b* are in agreement with Sorby and Baartmans⁸ that found no effects of previous work experiences. While not strictly statistically significant, there seems to be some effect of previous CAD/CAM scores with those having taken more than one such course scoring higher than those in their first such course. However, this effect size (0.343) is small²⁴. To further examine the effect of previous CAD/CAM courses on spatial ability two correlations were tested. The number of courses was correlated with the Pre-test score ($N = 152, r = 0.112, p = 0.169$) and the difference between the Post-test and the Pre-test ($N = 143, r = 0.035, p = 0.682$). Neither of these correlations was significant.

To assess the effect of the examined courses on spatial ability (*R2*) Pre-test and Post-test differences were examined by course. In this particular case, those co-enrolled in both courses are analyzed as a specific group. The results for the 3 course groupings are shown in Table 4. There were no significant differences in Pre-test and Post-test scores for any of the course groupings. This would suggest a negative response to *R2a* and *R2b*. Previous CAD/CAM course experience, as detailed above, does have effect on spatial visualization ability. This provides limited support for an affirmative response to *R2c*.

Finally, the role of spatial ability on performance in these courses was assessed using correlations between course performance and Pre-test and Post-test scores. In the case of the CAD Course Practical (overall data), both the Pre-test score ($N = 83, r = 0.402, p < 0.001$) and Post-test score ($N = 89, r = 0.290, p = 0.006$) were significantly positively correlated. This provides partial support for an affirmative answer to *R3*. In the case of CAM Course performance, only the Post-test score was correlated with laboratory grades ($N = 79, r = 0.261, p < 0.020$); the Pre-test score was not ($N = 80, r = 0.141, p = 0.212$). This provides support for an affirmative response to *R3a*. Finally, to assess the effect of a 3D CAD Course Practical, the correlations between performance in the two situations were compared. For the 2D drawing CAD Course Practical (Semester 1) the correlation was positive and significant with the Pre-test

score ($N = 41$, $r = 0.450$, $p = 0.003$) and the Post-test score ($N = 44$, $r = 0.358$, $p = 0.017$). This provides support for a positive answer to *R3b*. For the 3D object CAD modeling Course Practical (Semester 2) the correlation was positive and significant with the Pre-test score ($N = 42$, $r = 0.356$, $p = 0.021$), but not the Post-test score ($N = 45$, $r = 0.197$, $p = 0.194$). This provides partial support for an affirmative response to *R3c*. Fisher's z test was used to compare the two correlations and they were not significantly different ($z = 0.49$; $p = 0.624$).

Discussion

Limitations and Future Work

Any conclusions or general findings from this work have to be viewed in light of the study's limitations. First, the Revised PSVT:R was not a graded component of either course. Students may not have taken it as seriously as they might have if it were to affect their grade; Sorby and Baartmans⁸ gather Post-test data as a graded component of the final exam. Second, the student population may suffer from survivor bias and might have saturated their spatial visualization abilities. Students that would have performed poorly on the Pre-test and thus might have experienced a positive impact of the CAD or CAM Course may have dropped out by the time of these third-year courses. Future work will attempt to scale extra credit with Revised PSVT:R test performance and gather data from more junior populations to ensure the effects of academic seniority in line with that reported by Kinsey *et al.*⁵ who found that upperclassmen scored better on the original PSVT. Future work will also attempt to gather spatial ability and job performance data from practicing engineers and machinists to see if there is a relationship between spatial ability and competence with CAx tools in the workplace.

Conclusions

The Revised PSVT:R was administered to a junior-level CAD Course and a junior-level CAM Course. This work attempted to investigate some aspects of spatial ability not currently detailed in the literature. These included the relationship between spatial ability and course performance in more senior students, the effect of spatial ability on a CAM course, and the effect of spatial ability on the ability to create 3D models in CAD as opposed to translating from 2D to 3D models or vice versa. Spatial visualization ability was positively correlated with the ability to translate a 3D object into a 3D model. The results indicate that the more senior student population may suffer from survivor bias and have saturated their spatial visualization ability. There were no significant improvements in Post-test versus Pre-test scores for any course grouping or the overall population. Spatial ability as measured by the Revised PSVT:R was positively correlated with both the CAD Course laboratory practical and the CAM Course laboratory grades. However, there was no significant difference between the correlations for the 2D and 3D laboratory practical in the CAD Course.

References

- [1] Dankwort, C.W., Weidlich, R., Guenther, B. & Blaurock, J.E., (2004). Engineers' CAx education - it's not only CAD. *CAD Computer Aided Design*, 36 (14), 1439-1450.
- [2] Frechette, S.P., (2011). Model based enterprise for manufacturing. *44th CIRP International Conference on Manufacturing Systems*, Madison, WI.

- [3] Norman, K.L., (1994). Spatial visualization--a gateway to computer-based technology. *Journal of Special Education Technology*, 12 (3), 195-206.
- [4] Mohler, J.L., (2008). A review of spatial ability research. *Engineering Design Graphics Journal*, 72 (2), 19-30.
- [5] Kinsey, B., Towle, E., Hwang, G., O'brien, E.J. & Bauer, C.F., (2006). The effect of spatial ability on the retention of students in a college of engineering and physical science *ASEE Annual Conference and Exposition, Conference Proceedings*.
- [6] Veurink, N. & Sorby, S.A., (2012). Comparison of spatial skills of students entering different engineering majors. *Engineering Design Graphics Journal*, 76 (3), 49-54.
- [7] Uttal, D.H., Meadow, N.G., Tipton, E., Hand, L.L., Alden, A.R., Warren, C. & Newcombe, N.S., (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, 139 (2), 352-402.
- [8] 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+387-392.
- [9] Sorby, S.A., (2005). Assessment of a "new and improved" course for the development of 3-d spatial skills. *Engineering Design Graphics Journal*, 69 (3), 6-13.
- [10] Martín-Gutiérrez, J., González, C.R. & Domínguez, M.G., (2012). Training of spatial ability on engineering students through a remedial course based on augmented reality *Proceedings of the ASME Design Engineering Technical Conference*, 219-225.
- [11] Ahn, I. & Workman, J., (2012). The role of experience in performance on spatial tests: Comparison of students and professionals. *International Journal of Fashion Design, Technology and Education*, 5 (3), 187-193.
- [12] Vandenberg, S.G. & Kuse, A.R., (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, 47 (2), 599-604.
- [13] Bennett, G.K., Seashore, H.G. & Wesman, A.G., 1973. Differential aptitude test. New York: The Psychological Corporation.
- [14] Leopold, C., Gorska, R.A. & Sorby, S.A., (2001). International experiences in developing the spatial visualization abilities of engineering students. *Journal for Geometry and Graphics*, 5 (1), 81-91.
- [15] Adanez, G.P. & Velasco, A.D., (2002). Predicting academic success of engineering students in technical drawing from visualization test scores. *Journal for Geometry and Graphics*, 6 (1), 99-109.
- [16] Anon, 1939. CEEB special aptitude test in spatial relations (mct). USA: developed by the College Entrance Examination Board.
- [17] Guay, R., 1977. Purdue spatial visualization test: Rotations. West Lafayette, IN: Purdue Research Foundation.
- [18] Yue, J., (2008). Spatial visualization by realistic 3D views. *Engineering Design Graphics Journal*, 72 (1), 28-38.
- [19] Yue, J., (2007). Spatial visualization by isometric view. *Engineering Design Graphics Journal*, 71 (2), 5-19.
- [20] Yoon, S.Y., 2011. Revised purdue spatial visualization test: Visualization of rotations (*Revised PSVT:R*).
- [21] Yoon, S.Y., 2011. *Psychometric properties of the revised purdue spatial visualization tests: Visualization of rotations (the Revised PSVT:R)*. Ph.D. Purdue University.

- [22] Maeda, Y. & Yoon, S.Y., (2011). Measuring spatial ability of first-year engineering students with the revised psvt:R *ASEE Annual Conference and Exposition, Conference Proceedings*.
- [23] Branoff, T.J. & Dobelis, M., (2012). The relationship between spatial visualization ability and students' ability to model 3d objects from engineering assembly drawings. *Engineering Design Graphics Journal*, 76 (3), 37-43.
- [24] Cohen, J., (1992). A power primer. *Psychological Bulletin*, 112 (1), 155-159.

Appendix – Demographic Survey

Name _____

1. Please check the computer-aided design (CAD) or computer-aided manufacturing (CAM) courses you have taken. If you are currently enrolled in any of the following courses, please put a "C" next to that course.

XXXX 105 _____ XXXX 407 _____ XXXX 408 _____
 XXXX 361 _____ XXXX 380 _____

Other (please describe): _____

2. Have you ever take a spatial visualization test before?

Yes No

3. Please specify your gender:

Female Male

4. Please state your age: _____

5. Have you had a professional work experience related to engineering (e.g., internship, co-op, etc.)?

Yes No

6. Have you had any technical employment and research experience related to engineering (e.g., machines shops, labs, project tasks, etc.)

Yes No