Spatial Skills Training Impacts Retention of Engineering Students – Does This Success Translate to Community College Students in Technical Education?

Ms. Susan Metz, Stevens Institute of Technology

Susan Staffin Metz is the Executive Director of Diversity & Inclusion and Senior Research Associate at Stevens Institute of Technology. She is a long time member of the Stevens community serving as executive director of the Lore-El Center for Women in Engineering and Science and in 1990 launching WEPAN (Women in Engineering Proactive Network), a national organization catalyzing change in the academic climate for women in STEM fields. Under Susan's leadership, both Stevens and WEPAN were recognized by the White House with the prestigious President's Award for Excellence in Science, Mathematics and Engineering Mentoring. She has substantially contributed to the national STEM diversity policy agenda through participation on boards including the National Academy of Engineering Diversity Task Force, National Science Foundation Engineering Directorate and consultant to the National Academy of Engineering's Center for Advancement of Scholarship in Engineering Education.

As PI or Co-PI on multi-institutional collaborative projects, Susan has secured nearly $10 million in grant funds and published or contributed to dozens of academic and scholarly papers, book chapters, conference proceedings and seminars on STEM diversity at the pre-college, college and workforce levels. She is a recipient of the Maria Mitchell Association's Women in Science Award and is a Fellow of the Association for Women in Science.

Tania Jarosewich, Censeo Group

Dr. Jarosewich leads program evaluation projects at Censeo Group. She was an associate director at the Indiana Center for Evaluation (Indiana University-Bloomington), postdoctoral research fellow at Duke University, and for many years worked as a school psychologist with the Cleveland Municipal School District. She is co-author of the Gifted Rating Scales, published by Elsevier and an author of a number of peer reviewed journal articles. She is an active member of the American Evaluation Association and a member of the Ohio Program Evaluators' Group program committee. Dr. Jarosewich received her PhD in School Psychology from Kent State University and a BA in Psychology from the University of Cincinnati.

Dr. Sheryl A. Sorby, Ohio State University

Dr. Sheryl Sorby is currently a Professor of Engineering Education at The Ohio State University and was recently a Fulbright Scholar at the Dublin Institute of Technology in Dublin, Ireland. She is a professor emerita of Mechanical Engineering-Engineering Mechanics at Michigan Technological University and the P.I. or co-P.I. on more than $9M in grant funding, most for educational projects. She is the former Associate Dean for Academic Programs in the College of Engineering at Michigan Tech and she served at the National Science Foundataion as a Program Director in the Division of Undergraduate Education from January 2007 through August 2009. Prior to her appointment as Associate Dean, Dr. Sorby served as chair of the Engineering Fundamentals Department at Michigan Tech. She received a B.S. in Civil Engineering, an M.S. in Engineering Mechanics, and a Ph.D. in Mechanical Engineering-Engineering Mechanics, all from Michigan Tech. Dr. Sorby has a well-established research program in spatial visualization and is actively involved in the development of various educational programs.

Adapting Tested Spatial Skills Curriculum to On-Line Format for Community College Instruction: A Critical Link to Retain Technology Students (SKIITS)

I. Introduction

Spatial Skills Instruction Impacts Technology Students (SKIITS)[1] is developing an online, transportable course that community colleges can use as a resource to offer spatial skills training to their students with a nominal investment of institutional resources. The course is based on research and materials funded by NSF that have successfully been used in face-to-face instruction in four-year universities.

SKIITS focuses on three research questions:
1. Can effective materials developed through earlier NSF funding to improve spatial skills be transformed into an *effective* set of online resources?
2. Does providing spatial skills training improve the retention of low-spatial-ability women in technician programs?
3. Does providing spatial skills training improve the retention of low-spatial-ability Black and Hispanic students in technician programs?

Faculty and administrators at four community college partners have implemented SKIITS from Fall 2014 through Fall 2017.

II. Prior Research

A. Spatial Visualization Related to STEM Fields

The ability to visualize objects and situations in one's mind and to manipulate those images is a cognitive skill vital to many career fields, especially those that require work with graphical images. A long history of research has highlighted the importance of spatial skills in technical professions such as engineering,[2] basic and structural chemistry,[3] computer aided design software,[4] using modern-day laparoscopic equipment in medical professions,[5] and interacting with and taking advantage of the computer interface in performing database manipulations.[6] There is evidence that spatial visualization skill predicts course selection and success in physics,[7,8] chemistry;[7,9] engineering[10,11] and geology.[12,13] Recent articles link spatial skills to creativity and technical innovation[14] and to success in programming.[15] Adolescent spatial reasoning skills predicted choice of STEM majors and careers above and beyond the effects of verbal and math abilities[16] and spatial ability emerged as a consistent and statistically independent predictor of selecting STEM related courses, graduate study, and other measures of STEM attainment. Thus it is now clear that "spatial ability plays a critical role in developing expertise in STEM…"[16] In fact, nearly fifty years ago, Smith[17] concluded that spatial skills play an important role in 84 different careers.

SKITTS builds on studies that have studied the role of spatial skills for success in four-year and graduate college degrees, expanding the focus to technical education. The need to focus on technical education is supported by work of another ATE project, *Individual Differences in Technological Proficiency*. "The spatial domain represents another important ability for technological education. Several tasks performed by technicians require highly developed spatial talent. Prints and schematics are one clear example. Reading a two-dimensional print and transferring the specifications of the print with different views onto a 3-dimensional part requires the ability to recognize patterns, sometimes when the part is not visible. Again, it is important for technological education programs to recognize that basic cognitive abilities, such as spatial visualization, are skills that make technician careers possible and satisfying for some."[18]

B. Gender and Socio-Economic Differences in Spatial Skills

There is a great deal of evidence to suggest that the 3D spatial visualization skills of women lag significantly behind those of their male counterparts.[19, 20, 21, 22, 23] These differences have been tied to environmental factors[24], differences in math performance,[25] and a combination of factors, including the type of toys a child played with, the type of sports they participated in, the type of K-12 courses a student enrolled in, and the types of computer games they played.

Spatial skills of minority students[26] and students from low socio-economic-status (SES) groups were significantly lower than the skills for students from middle or high SES groups.[19, 27] Levine[27] also reported no gender differences for students in the low-SES groups, but significant gender differences for students from middle and high SES groups. Poorly developed spatial skills among students in these groups could have serious implications for broadening participation in STEM, particularly in technician programs.

C. Evolution of Spatial Skills Course Development at Michigan Technological University

SKITTS draws on work performed over two decades at Michigan Technological University. With NSF funding, Baartmans and Sorby[28] developed a course for the development of 3-D spatial skills for first-year engineering students who arrived at the university with poorly developed spatial skills. The course has been offered continuously since 1993. A longitudinal study conducted in 2000[11] found that for students who initially demonstrated poorly developed spatial skills, enrollment in the spatial skills course improved success in graphics courses by a half-letter grade. Retention rates for women improved significantly and retention rates for men also improved, but not by a statistically significant margin. Another study showed that students who initially failed the PSVT:R and enrolled in the spatial skills course improved their performance in a number of courses, including Engineering I, Engineering II, Calculus I, Computer Science as well as in their overall GPA[29] and earned grades higher than those of students who had marginally passed the PSVT:R with a score of 60-70%.[30] Improvement in grades was not due solely to self-selection of students into the spatial skills course since the course was required for engineering students who failed the PSVT:R during orientation beginning in 2009 and similar results (i.e., higher grades and retention rates for female students) were also obtained through this analysis (manuscript in preparation). Further, the retention rates of women students who failed the PSVT:R and completed the spatial skills course improved compared to those who failed the PSVT:R but did not enroll in the course.[31]

III. SKIITS Course Materials Development

Although the evidence in favor of providing spatial skills training is strong, lack of resources at most community colleges across the nation is a deterrent to the adoption of such a course in technician education. SKIITS is addressing this need by developing and testing the effectiveness of a course that includes online lessons that can be delivered asynchronously to community college students. The project team is also refining and testing the effectiveness of an iPad app to enable students to use their fingers or a stylus for sketching exercises, a critical component that promotes spatial skills development.[32, 33]

The curriculum being used includes ten spatial skills modules[34], which SKIITS is enhancing in the following ways:

- **Revising current online resources.** The team is updating existing modules (i.e., background and exercises) with the latest technologies so that students' responses to exercises are recorded and available to the faculty member for grading and feedback.
- **Video mini-lectures**. The team has professionally developed 2-5 minute video introductions to module topics, which are available in common formats for use with a variety of computer platforms.
- **Video how-to instructions.** Additional videos provide step-by-step instruction for difficult concepts for several exercises, including the first isometric sketch, which can be daunting for students with weak spatial skills.
- **Engagement tracking.** Instructors can login and determine how much time students spend on each activity. This data will inform optimal design of the materials available to students.
- **iPad sketching exercises.** iPad touch-screen capability enables the development of sketching exercises that can be completed with fingertips or a stylus instead of pencil and paper. Alpha versions for sketching exercise have been developed.[35] Planned enhancements include a feedback mechanism to provide faculty automated feedback regarding students' sketches. The workbook pages with sketching exercises will also be available as pdf files for students who do not have an iPad. In this project, we will test both methods of delivering sketching exercises and compare the results obtained through each.

Software and Workbook Modules

1) Surfaces and Solids of Revolution
2) Combining Solids
3) Isometric Sketching
4) Orthographic Projection
5) Orthographic Projection with Inclined and Curved Surfaces
6) Pattern Folding
7) Rotation of Objects about One Axis
8) Rotation of Objects about Two or More Axes
9) Reflection and Symmetry
10) Cross-Sections of Solids

IV. Implementing Curriculum at Participating Institutions

Benefits of an online format include the ability to accommodate complex student schedules and implement the course with a lower level of resources. That said, the study is monitoring outcomes and assessing whether an exclusive on-line format yields the results observed with face-to-face or hybrid course delivery.

From Fall 2014 to Spring 2016, four community colleges identified a set of courses each semester in which spatial skills were thought to be an important component. The courses covered a variety of topics in a variety of technical education skills areas including: Introduction to Programming, Advanced Programming, Introduction to Engineering, Design and Creation of Games, Introduction to Geographic Information Systems, Robotic Fundamentals, Computer Aided Design Graphics, Building Information Modeling Architecture, Modeling and Animation, 3D Game Development, Engineering Graphics, Architectural Drafting, Electronic Fundamentals with Computer Applications, and more. Students in each of these courses were invited to complete the Purdue Spatial Visualization Test: Rotations (PSVT:R) at the start of the semester and again at the end to select students for participation, to monitor outcomes, and to provide data for a comparison group of students who did not participate in the spatial skills intervention. Students who correctly answered fewer than 60% of the items were invited to participate in a supplemental spatial skills course offered on campus.

In Spring 2015, the cut-off score for participating in the course was increased to students who correctly answered fewer than 70% of the PSVT:R items in order to increase the number of students eligible to participate in the study. Research evidence supports this increased cut-off score. In a 2011 study, Veurink and Sorby examined various factors of student success in terms of their PSVT:R score during orientation. They found that the students who marginally passed the PSVT:R, scoring between 60-70%, likely would have benefitted from participation in the spatial skills course.[30]

Participation in the PSVT:R assessments and course were voluntary. Each institution decided when, over how many sessions, and how to organize the curriculum. Typically, the 10-module curriculum was offered over the course of four or five days spread out over several weeks.

Students who participated in the spatial skills course completed a survey, either through an online link, course management system, or as a paper and pencil task, to provide feedback about the course and their perceptions about its impact. Analysis of the survey results and student outcome data has included descriptive statistics and ANOVAs to compare changes in PSVT:R scores for students who completed the spatial skills training and students who did not participate in the course. Interview data were coded to identify common themes across institutions.

V. Eligibility and Participation

Table 1 summarizes information about the gender of students who completed the PSVT:R pre assessment, were eligible to participate in the course, completed the spatial skills course, and completed a PSVT:R post assessment. Not all students completed the PSVT:R pre and post assessments.

Table 1. Students by Gender

Gender	PSVT:R pre (all)	% eligible	N completed	PSVT:R post (all)
Male	18.52 (N=982)	59% (N=580)	147	19.92 (N=498)
Female	14.97 (N=181)	82% (N=149)	38	17.12 (N=94)
Blank	16.74 (N=46)	65% (N=30)	4	18.62 (N=45)
Total	**17.96 (N=1,209)**	**63%(N=760)**	**189**	**19.41 (N=627)**

Note: Not all students completed the voluntary PSVT:R pre and post assessments

A statistically significantly higher percentage of female students who completed a pre-test (82%) as compared to male students (59%) was eligible for the spatial skills course based on PSVT:R pre-test scores ($\chi2(3)$ =36.10, p=.000).

V. Outcomes of Course Participation

One-hundred eighty-nine students completed the spatial skills course in four institutions between Fall 2014 and Fall 2017. Table 2 illustrates the outcomes (i.e., PSVT:R scores, PSVT:R gains, course grades) for all students, students eligible to participate in the course (<60% on PSVT:R in Fall 2014 and <70% in Spring 2015 – Fall 2017), and those not eligible for the course.

Table 2. Outcomes for Students Eligible and Not Eligible for the Course

	PSVT:R pre	PSVT:R post	PSVT:R gains
Completed spatial skills training	14.31 (N=156)	18.18 (N=146)	3.79 (N=146)
Comparison group	13.64 (N=547)	15.85 (N=197)	2.03 (N=211)

Among the group who completed the spatial skills course, a vast majority, 93% (N=176), of students completed both a pre and post assessment. However, among all students in the group, only 45% (N=596) completed both the pre- and post-PSVT:R assessments. A statistically significant difference was evident in the post PSVT:R scores (F(1, 338) = 13.09, p=.000) between eligible students who completed the spatial skills training (Mean = 18.18, 61% items correct) and eligible students who did not complete spatial skills course (Mean = 15.85, 53% items correct). The spatial skills workshop intervention had a significant impact on the skills of students who completed the training program.

VI. Next Steps

Project implementation will continue with the spatial skills course delivered through Spring 2017. The study will continue to examine the implementation and outcomes of the course and monitor student PSVT: R scores. The study will also examine grades, retention, and progress towards graduation of eligible students who completed the spatial skills training and the comparison group. Research with community college partners will extend for one additional semester to increase the student sample size and subsequent strength of the results.

A key variable that the study will examine will be the impact of completing the spatial skills course on persistence in the course of study. The project team's hypothesis is that if students strengthen spatial skills and earn a higher grade in their credit-bearing course this will subsequently lead to greater persistence and degree completion. The community college partners are collecting data on student enrollment from semester to semester to allow for this analysis.

Another area of interest in the study is examining the impact of using the iPad for sketching practice on student outcomes. When there is a sufficient sample size, outcomes of students who use the iPad for sketching and students who engage in hand sketching will be examined. We will also be able to examine individual student engagement with the iPad sketching to determine how students use the tool. Instructor interviews and student surveys will be part of this analysis.

The final area of study will be to continue to examine how the structure and delivery of the course affect student engagement and outcomes. The project team will work with community college partners to articulate the structure of the hybrid course that instructors are offering to encourage replication. Ultimately, the project team believes that embedding spatial skills activities into core courses is key to widespread success of this intervention strategy. One community college partner has integrated the spatial skills course into a required course rather than offering it as a stand-alone supplemental course. In this structure, all students work through the spatial skills training exercises. Given the large percentage of students in the sample who earned a poor grade on the PSVT: R – 62% across the years – and the low percentage of eligible students who complete the additional course – approximately 20% of all eligible students – there is an opportunity to reach more students who can benefit from this intervention. The study will continue to measure the success of the embedded spatial skills activities and identify mechanisms that could facilitate this method of delivery with the other partner schools.

References

1. Adapting Tested Spatial Skills Curriculum to On-Line Format for Community College Instruction: A Critical Link to Retain Technology Students (HRD# 1407123) was funded by the National Science Foundation (NSF) in July of 2014.

2. Maier, P. H. (1994). Raeumliches vorstellungsvermoegen. Frankfurt A.M., Berlin, Bern, New York, Paris, Wien: Lang.
3. Barke, H.D. (1993). Chemical education and spatial ability. *Journal of Chemical Engineering, 70(12): 968-971*.

4. Sorby, S. A. (2000). Spatial abilities and their relationship to effective learning of 3-D modeling software. *Engineering Design Graphics Journal, 64(3), 30-35*.
5. Eyal, R. & Tendick, F. (2001). Spatial ability and learning the use of an angled laparoscope in a virtual environment. In J. D. Westwood et al, (Eds.) *Medicine Meets Virtual Reality (*pp. 146-152). Amsterdam: IOS Press.

6. Norman, K.L. (1994). Spatial visualization-A gateway to computer-based technology. *Journal of Special Educational Technology, XII(3), 195-206.*
7. Talley, L.H. (1973). The use of three-dimensional visualization as a moderator in the higher cognitive learning of concepts in college level chemistry. *Journal of Research in Science Teaching, 10, (3) 263-269.*

8. Kozhevnikov, M., Motes, M., & Hegarty, M. (2007). Spatial visualization in physics problem solving. *Cognitive Science, 31(4), 549-579.*

9. Wu, H, & Shah, P. (2004). Exploring visuospatial thinking in chemistry learning. *Science Education, 88(3), 465-492*.

10. Duesbury, R. & O'Neil, H. (1996). Effect of type of practice in a computer-aided design environment in visualizing three-dimensional objects from two-dimensional orthographic projections. *Journal of Applied Psychology 81(3): 249-260*.

11. Gerson, H., Sorby, S., Wysocki, A., & Baartmans, B. (2001). The development and assessment of multimedia software for improving 3-D spatial visualization skills. *Computer Applications in Engineering Education, 9 (2) 105-113*.

12. Kali, Y. & Orion, N. (1996). Spatial abilities of high-school students in the perception of geologic structures. *Journal of Research in Science Teaching, 33, 369-391*.

13. Orion, N., Ben-Chaim, D. & Kali, Y. (1997). Relationship between earth science education and spatial visualization. *Journal of Geoscience Education 45: 129-132.*

14. Kell, Harrison, J., Lubinski, D., Benbow, C. P., & Steiger, J. H. (2013). Ceativity and Technical Innovation: Spatial Ability's Unique Role. *Psychological Science*, 24.9, 1831-1836. http://pss.sagepub.com/content/early/2013/07/10/0956797613478615, DOI: 10.1177/0956797613478615

15. Jones, S. & Burnett, G., (2008). Spatial ability and learning to program. *Human Technology, Vol. 4 (1), pp. 47-61.*

16. Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, *101*(4), *817-835*. DOI:10.1037/a0016127

17. Smith, I. M. (1964). Spatial ability - Its educational and social significance. London: University of London.

18. Hull, Darrell M., Glover, Rebecca J., & Bolen, Judy A. (2012). Indivudal Differences in Technological Proficiency: Project Findings.

19. Casey, M.B., Pezaris, E., & Nuttall, R.L. (1992). Spatial ability as a predictor of math achievement: the importance of sex and handedness patterns, *Neuropsychologia*, *30*, *35-40*.

20. Halpern, D., (2000). Sex differences in cognitive abilities, Third Edition. Mahwah, NJ: Lawrence Erlbaum Associates.

21. Linn, M. & Peterson, A. (1985). Emergence and characteristics of sex differences in spatial ability: A meta-analysis. *Child Development, 56(6), 1479-1498.*

22. Lippa, R.A., Collaer, M.L., & Peters, M. (2010). Sex differences in mental rotation and line angle judgments are positively associated with gender equity and economic development across 53 nations. *Archives of Sexual Behavior, 39(4), 990-997.*

23. Voyer, D., Voyer, S., & Bryden, M. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin, 117, 250-270.*

24. Fennema, E., & Sherman, J.A. (1977). Sexual stereo-typing and mathematics learning. *The Arithmetic Teacher, 24(5), 369-372*.

25. Tartre, L.A. (1990). Spatial skills, gender, and mathematics. In E. H. Fennema & G. C. Leder (Eds.), *Mathematics and Gender*, (pp. 27-59). New York, NY: Teachers College Press.

26. Study, N. E. (2006). Assessing and improving the below average visualization abilities of a group of minority engineering and technology students. *Journal of Women and Minorities in Science and Engineering, 12 (4) 363-374.*

27. Levine, S. C., Vasilyeva, M., Lourenco, S. F., Newcombe, N. S., & Huttenlocher, J. (2005). Socioeconomic status modifies the sex difference in spatial skill. *Psychological Science,16(11), 841-845.*

28. Sorby, S. A. & Baartmans, B. J. (1996). A Course for the Development of 3-D Spatial Visualization Skills. *Engineering Design Graphics Journal, 60(1), 13-20*.

29. Sorby, S. A. (2011). Developing Spatial Thinking. Independence, KY: Cengage Learning. Retrieved from http://www.cengagebrain.com/shop/en/US/storefront/US?cmd=CLHeaderSearch&fieldValue=9781133623014

30. Veurink, N. L. and Sorby, S. A. (2011). Raising the bar? Longitudinal study to determine which students would benefit most from spatial training. 118th American Society for Engineering Education (ASEE) Annual Conference and Exposition. Vancouver, BC.

31. Sorby, S. A. (2005). Impact of Changes in Course Methodologies on Improving Spatial Skills. *International Journal for Geometry and Graphics, 9(1), 99-105.*

32. Sorby, S. A. (2009). Education Research in Developing 3-D Spatial Skills for Engineering Students. *International Journal of Science Education, 31(3), 459-480.*

33. Sorby, S. A., and Gorksa, R. A. (1998). The effect of various courses and teaching methods on the improvement of spatial ability. *Proceedings of the Eigth International Conference on Engineering Computer Graphics and Descriptive Geometry, Austin, TX, USA, 252-256.*

34. Sorby, S.A. (2015). Spatial Course Learning Resources. Higher Education Services. Retrieved from http://www.higheredservices.org/spatial-course-materials/

35. Delson, N. (2015). Tracking Student Engagement with a Touchscreen App for Spatial Visualization Training and Freehand Sketching. 122nd American Society for Engineering Education (ASEE) Annual Conference and Exposition. Seattle, WA.

36. Touro University of California Registrar. (2017). Grade Scale. Retrieved from http://studentservices.tu.edu/_resources/docs/registrar/formspage/Grade_Scale.pdf