2018 ASEE Annual Conference & Exposition
June 24-27, 2018
Salt Palace Convention Center
Salt Lake City, UT

Paper ID #21180

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

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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] developed an online, asynchronous, accessible-from-anywhere 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 created with the support of NSF funding that were successfully 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 students, including women in technician programs?
3. Does providing spatial skills training improve the retention of low-spatial-ability students, including students traditionally underrepresented in technician programs?

Faculty and administrators at four community college partners 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. Nearly fifty years ago, Smith[17] concluded that spatial skills play an important role in 84 different careers. 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]

SKIITS builds on studies that examined the role of spatial skills in supporting success in four-year and graduate college programs, expanding the focus to technical education. The need to focus on technical education is supported by the work of another ATE project, *Individual Differences in Technological Proficiency,* which suggested that, "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 Socioeconomic 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 the types of toys with which a child played, sports in which they participated, K-12 courses in which a student enrolled, and computer games with which they played.

Similarly, evidence also suggests that spatial skills of minority students[26] and students from low socioeconomic status (SES) groups are significantly lower than spatial skills of students from middle or high SES groups.[19, 27] Although Levine[27] reported no gender differences for students in the low-SES groups, the research indicated significant gender differences between students from middle and high SES groups. Poorly developed spatial skills among students in groups typically underrepresented in STEM programs and careers could have serious implications for broadening participation in STEM, particularly in technician programs.

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

SKIITS 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. Similar results of higher grades and retention rates for female students were also obtained through this project (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, few community colleges offer this type of training. Lack of resources at most community colleges across the nation is a deterrent to the adoption of such a course in technician education. To address this need, SKIITS developed and tested the effectiveness of a course that includes online spatial skills lessons that could be delivered asynchronously to community college students. As a part of this online asynchronous course delivery, the project team also refined and tested the effectiveness of an iPad app in which students use their fingers or a stylus for sketching exercises. Instructors have immediate access to students' progress in sketching, a critical component of spatial skills development.[32, 33]

The SKIITS project enhanced the ten spatial skills modules[34] (Figure 1) of the existing curriculum in the following ways:

- **Revising current online resources.** The team updated 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 developed 2-5 minute video introductions to module topics, are available in common formats for use with a variety of computer platforms.
- **Video how-to instructions.** Additional videos provide step-by-step instructions for difficult concepts for several exercises, including the first isometric sketch, which can be daunting for students with weak spatial skills.
- **Engagement tracking.** Data about student engagement with the online materials informs instructors about how much time students spent on each activity, and the project team about how to optimize the design of the materials.
- **iPad sketching exercises.** The project team developed an iPad app that allows students to sketch exercises with their fingertips or a stylus instead of pencil and paper.[35] Enhancements to the app included a mechanism to provide faculty automated feedback about students' sketches and persistence in sketching. Workbook pages with sketching exercises are also available as pdf files for students who do not have an iPad.

Figure 1.

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

The study examined the extent to which the online course format accommodated complex student schedules and decreased the level of institutional resources needed to implement the course. Along with an analysis of course implementation, the study also monitored outcomes and assessed whether an exclusive on-line format would yielded the results observed with face-to-face or hybrid course delivery.

From the fall 2014 semester to the fall 2017 semester, four community colleges identified a set of courses in which spatial skills were an important component. The courses covered a variety of topics in technical education, 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. This assessment was used 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 selected as correctly answering fewer than 70% of the PSVT:R items reflecting research evidence that supported this increased cut score. In a 2011 study, Veurink and Sorby examined various factors of student success based on scores of the PSVT:R that students completed during orientation. They found that the students who marginally passed the PSVT:R, scoring between 60-70% likely would have benefitted from completing the spatial skills course.[30]

Participation in the SKIITS 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 completed the spatial skills course responded to a survey, through an online link, course management system, or as a paper and pencil task, to provide feedback about the course and perceptions about its impact. Analysis of the survey results and student outcome data has included descriptive statistics and ANOVA to compare changes in PSVT:R scores for students who completed the spatial skills training and students who did not participate in the course.

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	18.56 (N=1,231)	58% (N=719)	176	19.83 (N=675)
Female	14.82 (N = 242)	82% (N=199)	42	16.70 (N=121)
Total	**17.94 (N=1,473)**	**62%(N=918)**	**228***	**19.36 (N=796)**

Note: Not all students completed the voluntary PSVT:R pre and post assessments; * not all students indicated gender

Statistically, a significantly higher percentage of female students who completed a pre-test (82%) as compared to male students (58%) was eligible for the spatial skills course based on PSVT:R pre-test scores ($\chi2(2) = 49.78$, $p=.000$).

V. Outcomes of Course Participation on PSVT:R and Course Grades

Two hundred twenty eight 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 eligible students (<60% on PSVT:R in Fall 2014 and <70% in Spring 2015 – Fall 2017) who completed and those who did not complete the course.

Table 2. Outcomes for Eligible Students

	PSVT:R pre	PSVT:R post	PSVT:R gains	Course Grade*
Completed course	14.27 (N=179)	18.30 (N=168)	3.89 (N=168)	3.20 (N=179)
Comparison group	13.73 (N=749)	15.68 (N=317)	1.62 (N=317)	2.58 (N=737)

*Course grade calculated on 0 (grade F) to 4.0 (grade A) scale

Among the group who completed the spatial skills course, a vast majority, 94% (N=214) of students completed both a pre and post assessment. However, among all students in the group, only 50% (N=762) completed both the pre- and post-PSVT:R assessments.

A statistically significant difference was evident in the post PSVT:R scores ($F(1, 483) = 21.65$, $p=.000$) between eligible students who completed the spatial skills training (Mean = 18.31, 61% items correct) and eligible students who did not complete spatial skills course (Mean = 15.68, 52% items correct). Students who completed the spatial skills workshop earned a higher grade in the credit-bearing course in which the workshop was offered ($F(1, 914)=55.16$, $p=.000$). All students who were eligible benefitted from the spatial skills course. The spatial skills workshop intervention had a significant impact on the skills of all students who completed the training program.

VI. Next Steps

A key variable that the study is examining is 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 final spatial skills course was delivered in fall 2017, a semester longer than originally planned. This no-cost extension allowed the project to gather an additional semester's worth of student course and persistence data. The community college partners are currently collecting data about student enrollment since the semester in which they completed the PSVT:R pre assessment, grades, and graduation status to allow for this analysis.

Another area the study is currently examining is the impact of using the iPad for sketching practice on student outcomes. As of fall 2017, there is a sufficient sample size to examine outcomes of students who used the iPad for sketching in comparison to students who engaged in hand sketching. Individual student engagement with the iPad sketching will also be examined to determine how students used the tool. Instructor interviews and student surveys will be part of this analysis.

The final area of study will be to examine how the structure and delivery of the course affected student engagement and outcomes. The project team will work with community college partners to articulate the structure of the hybrid course that instructors offered 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 in the final two semesters integrated the spatial skills course into a required course rather than offering it as a stand-alone supplemental course. In this structure, all students worked 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 completed the additional course – approximately 25% 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.

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