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

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I. Introduction

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. The goal of SKIITS (Spatial Skills Instruction Impacts Technology Students) is to develop an online, fully transportable course that community colleges can use as a resource to offer spatial skills training to their students cost effectively and 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 minority and students in technician programs?

Faculty and administrators at five community colleges are partnering to implement SKIITS: Baltimore County Community College (beginning in 2016), DelMar Community College, Gateway Community College, McHenry County College, and Tidewater Community College. Faculty are administering the Purdue Spatial Visualization Tests: Visualization of Rotations (PSVT:R)[1] assessment in select courses to identify students with weak spatial skills; organizing and offering the spatial skills training course for eligible students; and collecting, compiling, and submitting assessment data to the project evaluator. The SKIITS project team is working with researchers, STEM diversity leaders and industry partners to further develop the low-cost material to respond to the needs of community college technician-education programs to retain more women and URM students.

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, or 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 Univesity

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[30] 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 for 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 asynchronysly to community colleges 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. These 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

- **Industry Examples of Spatial Skills.** Each module will include short video and/or written "inspirational" segments about the importance of well-developed spatial skills for successful technician careers.

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.

During the first year of SKIITS implementation, three community college partners (DelMar Community College, McHenry County College, and Tidewater Community College) identified a set of courses 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 Geographic Information Systems, Robotics Fundamentals, Design and Creation of Games, Computer-Aided Design Graphics, Building Information Modeling Architecture, Parametric Modeling Solidworks, Blueprint Reading for Manufacturing, Civil Engineering Drafting, Electronic Fundamentals with Computer Applications, and Electrics Circuits. Students in each of these courses completed the PSVT:R at the start of the semester and again at the end to provide evidence of outcomes and a set of comparison data. Students who correctly answered fewer than 60% of the items were invited to participate in a supplemental spatial skills course offered on campus.

In this first iteration, faculty tested the traditional, face-to-face course model, collected data about student engagement and outcomes, and planned for online implementation. 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 because there is research evidence to support this cut-off[30] and the team wanted to increase the number of students participating in the study. 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. Instructors tried to accommodate student schedules by repeating course sessions on several days and at different times. However, a number of students began the course but did not finish.

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. Descriptive statistics of the student survey and student outcome data were calculated and an ANOVA of score gains on the PSVT:R was calculated to compare the relative growth and final course grades of the students in the spatial skills course as compared to students who did not participate in the course. Interview data were coded to identify common themes across institutions.

V. Eligibility and Participation

Tables 1 and 2 summarize information about the gender and race 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 eligible who completed	PSVT:R post (all)
Male	18.44 (N=325)	52%	33	19.73 (N=143)
Female	16.81 (N=110)	65%	12	19.43 (N=28)
Blank	17.93 (N =41)	54%	2	18.55 (N=20)
Total	**18.02 (N=476)**	**55%**	**47**	**19.57 (N=191)**

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

Table 2. Students by Race

Race	PSVT:R pre (all)	% Eligible	N eligible who completed	PSVT:R post (all)
White	19.44 (N=251)	47%	26	20.14 (N=118)
Hispanic	17.16 (N=122)	63%	13	18.36 (N=25)
African American	14.43 (N=49)	76%	5	16.92 (N=12)
Asian	18.00 (N=14)	5%	1	22.70 (N=10)
Other	16.15 (N=40)	56%	2	18.42 (N=27)
Total	**18.02 (N=476)**	**55%**	**47**	**19.57 (N=191)**

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

A statistically significantly higher percentage of female students (65%) as compared to male (52%) was eligible for the spatial skills course based on mean PSVT:R scores on the pretest ($\chi^2(1)=6.29$, p=.012). Similarly, a higher percentage of Hispanic (63%) and African American students (76%) as compared to white students was eligible for the course ($\chi^2(1)=18.84$, p=.001).

V. Course Participation Outcomes

Forty-seven students completed the spatial skills course in three institutions in the 2014-2015 school year. Table 1 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), and those not eligible for the course.

The overall gain in PSVT:R scores for all students who completed both a pretest (mean= 17.74) and a post test (mean=19.57) was statistically significant t(171) = -4.86, *p*=.000, with a noticeable (medium) effect size (*Cohen's d* = .74). For students eligible to participate, whether they did or did not participate, in the course with both PSVT:R pre- and post-test scores, the average change in PSVT:R score was not statistically higher F(1, 95) = 0.231, *p*=.632.

One of the project partners suggested that one reason for the small change in PSVT:R scores could be lack of motivation at the post-test and in subsequent course implementations, the PSVT:R became a course expectation rather than an added activity.

Although the change in PSVT:R did not differ significantly for eligible students whether or not they participated in the course, the average final course grade of eligible students who completed the course (N=47, $\bar{X}$= 2.91) was statistically significant, higher than the average grade of eligible students who did not complete the course (N=186, $\bar{X}$= 2.35; F(1, 233) = 4.6212, *p*=.041, *r*=.01). The effect size of this difference was small.

VI. Next Steps

Project implementation continued with the spatial skills course delivered in Fall 2015 with four community college partners and currently beginning with all five community college partners for the third time in January, 2016. There is some experimentation occurring with regard to course delivery and it varies among the institutions. In several institutions, students watch the course videos on their own and then meet with faculty to get additional assistance, while in others faculty continue to deliver a significant part of the curriculum to students face to face. At two institutions, students are using the iPad app for sketching, while in three institutions students are hand-sketching. The level of faculty support also varies, with regularly-scheduled classes in some institutions, drop-in times in the computer labs in others, and independent work in the final setting. There is a justifiable reluctance among faculty instructors to move exclusively to the on-line format of the spatial skills course at this stage. The study will continue to examine the implementation and outcomes of the course and monitor student PSVT:R scores, grades, retention, and progress towards graduation.

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