Longitudinal Results from Spatial Skills Training Interventions with Pre-College Students

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ABSTRACT *- In 2004, the author obtained a grant from the National Science Foundation to test the curricular materials previously developed for use with first-year engineering students with audiences outside engineering. One of the audiences with which the materials were tested was students in middle and high school. In these studies, the students demonstrated significant improvements in spatial skills and rated the materials favorably in terms of ease of use and fostering understanding. This paper outlines the results obtained from a longitudinal study that was recently conducted whereby grades in follow-on mathematics and science courses were examined for each group of students. In each case, a similar comparison group was identified and their performance in these follow-on courses was also examined.*

I. Background

According to the Social Cognitive Career Theory, one of the most significant predictors of career choice is self-efficacy. From cognitive psychology, it is known that self-efficacy is formed by a person's experiences in four domains—mastery experiences, vicarious experiences, social persuasions, and physiological states. Mastery experiences occur when a person successfully completes a specific type of problem or task. Previous successes lead a person to believe that he or she can tackle a similar problem in the future. Vicarious experiences occur when an individual sees someone else completing a task (i.e., a model) and believes that she or he could perform equally as well. Social persuasions include the supporting people in an individual's life—teachers, mentors, peers, or parents. If parents or teachers send messages regarding an individual's ability to perform certain tasks, that person begins to believe that they are indeed capable of performing the task. Finally, if a person has a physiological reaction to a task, such as a feeling of anxiety when taking a test, then this physical state impacts their ability to perform the task.

Self-efficacy refers to a person's belief that he or she is capable of taking action to achieve a certain goal, such as completion of a college degree. Self-efficacy is more than just self-confidence, and is situation specific and therefore can be examined related to career goals or subject-matter goals. For example, Britner and Pajares (2006) performed a study of self efficacy in middle school students, supporting the notion that mastery experiences signicantly predict "science self-efficacy". The concept of self-efficacy has by researched within numerous situations, including computer self-efficacy, math self-efficacy, health behavior self-efficacy and Engineering self-efficacy. Engineering self-efficacy is a person's belief that they could successfully navigate the engineering curriculum and eventually become a practicing engineer. Numerous studies examining the role of self efficacy in students' pursuit of engineering careers have generally found a positive correlation between self-efficacy and academic achievement in engineering disciplines. For example, it has been found that one's self-efficacy beliefs influence effort, persistence, and perseverance in goal attainment (i.e., Bandura & Schunk, 1981; Bouffard-Bouchard, 1990; Schunk & Hanson, 1985). Similar findings reveal that high self-efficacy beliefs influence the academic persistence necessary to maintain high academic achievement amongst college students enrolled in science and engineering courses (i.e., Lent, Brown, & Larkin, 1984; 1986)

In developing self-efficacy beliefs, it is likely that spatial skills play a role in the mathematics and science courses in which our students enroll. Since most STEM fields are highly visual, it is likely that students with poorly developed spatial skills will have few "positive" mastery experiences in these subjects. Poor mastery experiences will therefore lead to poor self-efficacy beliefs regarding these topics in school. Based on their self-efficacy beliefs, students are likely to do poorly on their next assignment, reinforcing their poor self-efficacy. Theoretically, improving self-efficacy beliefs where spatial skills are a factor will in turn likely lead to improved performance and motivation for study.

II. Current Study

In 1998, nine multimedia software and workbook modules were developed with funding from the National Science Foundation aimed at helping students improve their 3-D spatial skills. The nine software and workbook modules are:1) isometric sketching, 2) orthographic projection, 3) paper folding, 4) rotation of objects about one axis, 5) rotation of objects about one or more axes, 6) reflection and symmetry, 7) cross-sections of solids, 8) surfaces and solids of revolution, and 9) combining solids. The software and workbook were used successfully in interventions with first-year engineering students over the past ten years and have been the topic of several papers presented at previous EDGD conferences. Beginning in the spring of 2005, the materials have been tested through a series of studies conducted with pre-college students. The recent studies were conducted with students in the middle school (approximate age of 13 years) and with students in the high school (approximate age of 16 years).

In October 2004, the author was awarded a research grant from the Gender in Science and Engineering program at the National Science Foundation. The purpose of this previous grant was to test the materials developed by Sorby and Wysocki with audiences other than first-year engineering students. One of the studies conducted through this grant was aimed at undergraduate students in majors outside engineering. Subjects in this study were primarily majoring in either computer science or biology (the two largest non-engineering majors at Michigan Tech) and the most significant finding from this study was that the software alone does not help students develop their 3-D spatial skills as well as when it is used in conjunction with the workbook.

Two other audiences were tested with this previous grant—middle school students in an integrated technology course and high school students in a geometry course. The software and workbook were found to be appropriate for use with both of these age groups through rigorous assessment. Students enjoyed working with the materials and their spatial skills improved significantly on a number of tests of spatial cognition.

Studies with Middle School Students

In the studies with middle school students, the materials were pilot-tested in spring 2005 and were again used in 2006 and 2007 during the regular offerings of an integrated technology course. Due to scheduling irregularities, the pilot group consisted of 14 honors 8th grade students; eleven of the students were female and three were male. In a longitudinal study conducted recently, grades and enrollment in follow-on math and science courses were examined. A comparison group, consisting of a "matched" group of honors students were selected who were a year younger than the pilot study group (i.e., they had been 8th grade students in 2004). In examining the longitudinal data, there were no significant differences in the grades obtained in follow-on math and science courses. All of the female students in both groups completed three years of high school math courses (only two math courses were required for graduation in Michigan at the time).

In the high school science courses in which these students enrolled, it appears that the female students in the pilot group enrolled in advanced mathematics and science courses at a greater participation rate than did the female students in the comparison group. The difference in participation rate is significant at the 90.5% confidence level. Table 1 contains the data from this longitudinal study regarding mathematics and science enrollment.

Table 1. Enrollment in Advanced Mathematics and Science Courses

	Pre-Calculus	Chemistry	Physics	Anatomy
Pilot Group (n=11)	8 (73%)	10 (91%)	7 (64%)	10 (91%)
Comparison Group (n=9)	8 (89%)	6 (67%)	5 (56%)	4 (44%)

In 2006, the materials were used in the integrated technology course for middle school students and statistically significant gains on several tests of spatial cognition were obtained. In 2007, the materials were again administered to 8th grade students with one significant modification—additional problems in isometric drawing, orthographic projection, and object rotation were developed and included in the instructional materials for the course. These extra problems enabled students to have additional time on task for these difficult topics.

There were four tests of spatial cognition administered to these students. One test measured mental rotation and a second test measured paper folding. The third test measured a student's ability to perceive what a cross-section of a solid would look like if sliced with an imaginary cutting plane. The fourth test measured a student's ability to understand isometric drawings from orthographic drawings and vice versa. The four tests were also administered to a similar comparison group in each year of the study. Correlations between test components were strongly significant, so a principal components analysis was used to combine the scores into one composite test score. Table 2 contains the results from this study disaggregated by gender.

Table 2. Pre-/Post-test Results for Middle School Students

Group	Gender	n	Mean Pre-Test	Mean Post-Test	Average Gain
Comparison Group	Female	68	41.0%	44.4%	3.4%
	Male	73	42.8%	49.0%	6.2%
2006 Treatment Group	Female	40	32.6%	43.4%	10.8%
	Male	40	51.6%	65.1%	13.5%
2007 Treatment Group	Female	28	49.4%	67.3%	17.9%
	Male	24	59.2%	75.6%	16.4%

The results from these studies indicate that the students who participated in the training activities had significantly higher gains in spatial skills compared to the students who did not undergo such training. Further, additional time on task solving spatial problems (2007 Treatment Group vs. 2006 Treatment Group) resulted in significantly higher gains for the girls but not for the boys who participated in the studies, narrowing the gender gap somewhat.

Studies with High School Students

In 2006 and in 2007, high school students enrolled in a standard geometry course completed the visualization software and workbook exercises. A longitudinal study was recently completed for the students in the 2006 cohort. In this case, a comparison group was identified consisting of students who had completed geometry in 2004 with the same teacher (this particular teacher did not happen to teach geometry in 2005). In this high school, geometry is "normally" taken in the 10th grade; however, students who are advanced may take geometry in the 9th grade and students who are "behind" take geometry in either the 11th or sometimes the 12th grade. Students who complete geometry who wish to continue in mathematics will take Advanced Algebra in their junior year and Pre-calculus in their senior year. Students enroll in Biology typically in their sophomore or junior year and may enroll in Chemistry or Physics after that if they wish to continue in science. At the time of this study, the state of Michigan required only two years of math and two years of science for graduation. At this high school, students who are not on the math and science "track" will typically enroll in Applied Algebra, Physical Science, or Integrated Science to complete their math and science requirements for graduation.

For the longitudinal study, grades in geometry as well as in several key advanced mathematics and science courses were noted. In this analysis, A=4.0, A-=3.65, B+=3.35, B=3.0 and so on. Table 3 contains the average grades in select mathematics and science courses for students who were enrolled in geometry during 2004 (no spatial skills training) and in 2006 (spatial skills training).

Table 3. Average Grades in Select Math and Science Courses

Course	No Spatial Skills Training (2004 Cohort, n=57)	Spatial Skills Training (2006 Cohort, n=44)
Geometry	2.30	2.53
Advanced Algebra	2.01	2.10
Pre-Calculus	2.62	2.97
Biology	2.04	2.34
Chemistry	2.77	2.52

From the data presented in Table 3, it appears that the students who went through the spatial skills training received higher grades on average than those who did not. However, in analyzing the data by gender, it appears that the higher grades were all due to higher grades for the boys compared to the girls in the classes.

In examining the data for the girls only, they were further subdivided into those who took geometry in 10th grade or earlier (on track) or those who took geometry in 11th grade or later (not on track). Table 4 includes enrollment data for these students. [In this table, percentages are computed as the percent of students in the original geometry course.]

Table 4. Enrollment in Follow-on Courses

	No Spatial Skills Training		Spatial Skills Training	
	On Track	Not On Track	On Track	Not On Track
Geometry	22 (100%)	8 (100%)	11 (100%)	11 (100%)
Advanced Algebra	16 (73%)	0 (0%)	7 (64%)	1 (9%)
Pre-Calculus	5 (23%)	0 (0%)	3 (27%)	0 (0%)
Biology	19 (86%)	0 (0%)	6 (54%)	5 (45%)
Chemistry	16 (73%)	0 (0%)	9 (82%)	1 (9%)

From the data presented in this table, it appears that the spatial skills training did not have a significant impact on girls enrolling in advanced mathematics and science courses for girls who were on track; however, it appears that the spatial skills training could have positively impacted enrollment in advanced courses for the girls who were not on track. It should be noted that for the girls not on track, even though they attempted advanced courses, they were not always successful in these courses (3 of the 7 total attempts resulted in failure). It is likely that by the time these girls reach high school, their mathematics and science self-efficacy beliefs are firmly established and they succeed (or not) and enroll (or not) based on these beliefs.

V. Conclusions

In analyzing the results from these previous studies, the following observations can be made:

- Spatial skills training appears to have a positive impact on middle school girls attempts at advanced math and science courses; however, it has little to no impact on this for high school girls.
- More time on task for middle school girls helped to narrow the gender gap somewhat in spatial skills.
- Spatial skills training did not positively impact grades in mathematics and science courses for girls in middle or in high school.

Based on the results from this previous research, it appears that the optimal age for girls to participate in spatial skills training is likely in middle school. High school interventions may be too late for most girls who have firmly established their poor self-efficacy beliefs about mathematics and science. [It should be noted that in the previous studies conducted by Sorby with first-year engineering students, that these young women, by virtue of their enrollment in an engineering program, already have well-established math and science self-efficacy, meaning that the intervention helped them reinforce a belief that they already held about themselves and did not help them establish their beliefs. Thus, the intervention "worked" for these students where it may not have worked for the average high school girl in the same way.]

VI. References

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