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EXTENDED ABSTRACT

Developing spatial cognitive skills among middle school students

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Introduction

In 1992, an initial grant was awarded from the National Science Foundation (NSF) in the US and a course was developed and implemented at Michigan Tech to help first-year engineering students to develop their 3-D spatial skills. The course syllabus was created with topics sequenced in a fashion known to enhance spatial skills. A textbook (Baartmans and Sorby 1995) was written in support of the class outline. Computer exercises that utilized computer-aided design software were developed as a part of this initial grant activity with exercises designed to reinforce topics from class lectures (Sorby and Baartmans 2000).

During freshman orientation in 1993, students who had declared majors of mechanical, civil, environmental, metallurgical, or general engineering were administered the PSVT:R (Guay 1977). In this initial year, a total of 96 out of 535 students failed the PSVT:R with a score of less than 60%. A random sample of 24 students who failed the PSVT:R was selected for participation in the experimental course and the remaining 72 students became the comparison group for the initial study.

In examining the results from the PSVT:R for this initial group of students, the following observations were made. Although women made up only about 17% of the group taking the PSVT:R, they were about 43% of the group failing the test, making women nearly three times as likely to fail the PSVT:R than their male counterparts. Furthermore, of the 45 students who received perfect scores, only three were women. Male–female differences in failure and perfect score rates were statistically significant ($P < 0.01$).

In January 1998, a new grant was awarded from the NSF to replace the computer exercises that were developed as part of the initial funding (that were based on CAD software) with stand-alone multimedia software modules. Along with this software, a workbook was developed with sketching problems similar to those found to be helpful in helping students to develop their spatial skills. The result is a set of materials that was published by Cengage Learning in July 2002. The software modules, included as a CD-ROM in the back of the workbook, are stand alone and work with either a Mac or a PC. The software and workbook have been rigorously assessed to determine their effectiveness in improving spatial skills and to determine their usability from both a student's and faculty member's perspective. Through this evaluation, the effectiveness of the materials has been demonstrated for the use with first-year engineering students (Gerson et al. 2001).

Other findings from longitudinal studies conducted with engineering students are: (1) students with weak spatial skills who participated in the spatial skills training course earned better grades in a variety of follow-on engineering, science, and mathematics courses when contrasted with a similarly chosen comparison group and (2) women with weak spatial skills who participated in the spatial skills training course were more likely to be retained at the university when contrasted with women in a similarly chosen comparison group (Sorby 2001).

Method

In October 2004, the author (along with T. Drummer, K. Hungwe, and P. Charlesworth) was awarded a research

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grant from the Gender in Science and Engineering program at the NSF. The purpose of this grant was to test the software and workbook materials with audiences other than first-year engineering students. One of the other audiences that used the software and workbook materials was middle school students in an integrated technology course. In the US, middle school students are generally 12–13 years old.

The materials were pilot-tested in spring 2005 and were again used in 2006 and 2007 during the regular offerings of the integrated technology course. In 2006, the materials were administered in the integrated technology course for middle school students and 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.

Due to scheduling irregularities, the pilot group in 2005 consisted of 14 honors 8th grade students; 11 of the students were female and three were male. During the 2006 and 2007 offerings, students were from a wide disparity in backgrounds (similar to what would be found in a typical middle school classroom).

The spatial skill-building materials were implemented as a part of the Integrated Technology course at Jeffers Middle School. Typically, the students spent 2–3 days each week working on a module, with the remainder of the course time spent on other topics. One to three class periods were required for each module.

For each module, the teacher first previewed the module introduction from the workbook with the students, emphasizing the important ideas they would acquire from the computer tutorial, and pointing out any sections where they should pay special attention. The teacher then observed and assisted the students as they completed the computer tutorial. Students who finished the computer tutorial early started to work on the workbook pages. Enough classroom time was allowed for the students to complete a majority of the workbook exercises in each module. The students were not required to complete all of the workbook exercises, but were required to stay on task and complete as many of the exercises as possible in the time allowed. The teacher continued to observe and assist the students as they worked the exercises.

As a result of limited access to computers, the students were grouped into pairs for the duration of the study. They worked in their partner pairs for both the computer and workbook exercises. The students were also given a set of snap cubes to use, to help them in visualizing the objects they were sketching.

Results

Students were asked to evaluate each module after completing it. In analyzing the data from this evaluation, some interesting observations can be made. The majority of the students felt that they understood the material and that they were given enough time to complete the exercises appropriately. Most students stated a preference for working with both the multimedia software and the workbook. This is in contrast to a similar question asked of non-engineering university students who participated in a study in the fall of 2004. The university students preferred to use the software alone for training purposes, even though it was the least effective mode for developing 3-D spatial skills. The workbook exercises and the software received high marks for nearly every module.

During the 2005 pilot study, students were administered the PSVT:R test only; there were four tests of spatial cognition administered to the students in 2006 and 2007. One test measured mental rotation (Guay 1977) and a second measured paper folding (Bennett et al. 1973). 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 (CEEB 1939). The fourth test measured a student's ability to understand isometric drawings from orthographic drawings and vice versa (Lappan 1981). The four tests were also administered to a similar comparison group in each year of the study. Figure 1 shows example problems from these tests.

For the 2005 pilot group, only the PSVT:R was administered as a pre- and post-test and due to the small number of male students in this group, results were not disaggregated by gender. In 2006 and 2007, correlations between test components were strongly significant, so a principal components analysis was used to combine the scores into one composite test score. Table 1 contains the results from this study disaggregated by gender [Recall that the pilot group was a non-representative sample of middle school students consisting primarily of honors students].

In a longitudinal study conducted recently, grades and enrollment in follow-on math and science courses were examined for the girls in the pilot group. A comparison group, consisting of a "matched" group of honors girls was selected who were a year younger than the pilot study group (i.e., they were 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 3 years of high school math courses (only two math courses were required for graduation in Michigan at the time).

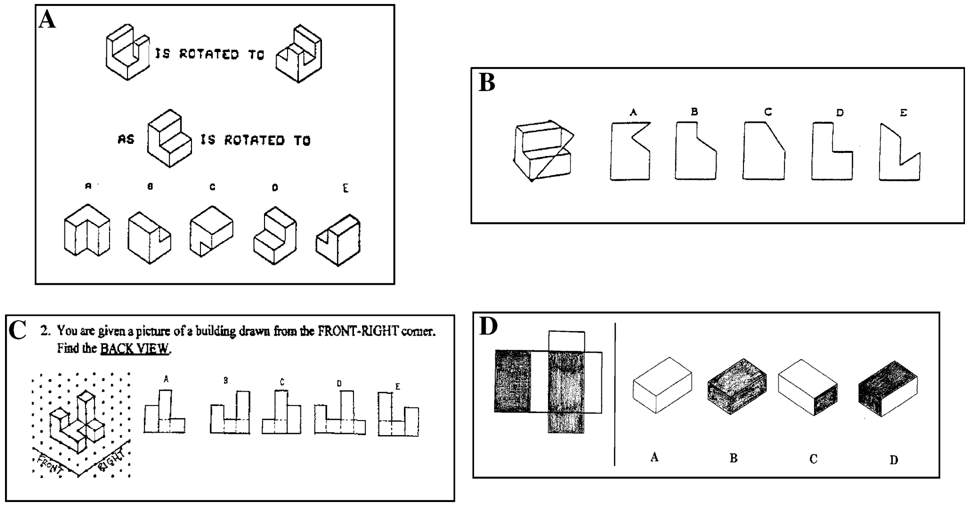

Fig. 1 Sample problems from **a** Purdue spatial visualization test: rotations (PSVT:R), **b** Mental cutting test (MCT), **c** modified Lappan test, and **d** differential aptitude test: space relations (DAT:SR)

Table 1 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
2005 Pilot group (PSVT:R only)	NA	16	63.6	82.9	19.3
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

In the high school science courses, 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. For the pilot group, girls participated in advanced courses (pre-calculus, chemistry, physics, and anatomy) at an overall rate of 79.5%; for the comparison group, the participation rate was 63.9%. The difference in participation rate is significant at the 90.5% confidence level.

Discussion

The software and workbook developed for a first-year engineering course were found to be appropriate for the use with middle school students through rigorous assessment. Students enjoyed working with the materials and their spatial skills improved significantly on a number of tests of spatial cognition. 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 middle school girls but not for the boys who participated in the studies, narrowing the gender gap somewhat.

Spatial skills training also appears to have a positive impact on middle school girls attempts at advanced mathematics and science courses. Girls who underwent the spatial skills training went on to enroll in more follow-on math and science courses than did girls in a similarly identified comparison group. In a separate research study conducted with high school girls by the author, no difference in follow-on enrollments were obtained for girls who had participated in spatial skills training compared to those who had not. The results from this research suggest that the optimal age for girls to participate in spatial skills training is likely in or around 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.

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