Developing 3-D Spatial Skills for K-12 Students

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ABSTRACT- *Three-dimensional spatial skills have been shown to be critical to success in engineering and other technological fields. Well-developed 3-D spatial skills are particularly important for success in engineering graphics courses. Further, 3-D spatial skills of women lag significantly behind those of their male counterparts, which could hinder their success in engineering graphics. At Michigan Tech, we have been offering a special course aimed at improving the 3-D spatial skills of engineering students, particularly women, since 1993. In a recent study, we have pilot tested the materials developed at Michigan Tech with a group of middle school students. This paper will summarize the findings obtained from our outreach to middle school students. Future plans for testing with additional K-12 audiences will be discussed.*

I. INTRODUCTION

Researchers have found that 3-D spatial skills are critical to success in a variety of careers, particularly in engineering and science [1-3]. For engineering, the ability to mentally rotate objects in space has been found to be of particular importance [4]. Unfortunately, of all areas of cognition, 3-D spatial skills still exhibit some of the most robust gender differences favoring males and the most pronounced gender differences are in the area of mental rotations [5-7]. For this reason poorly developed 3-D spatial skills could be a hindrance to the success of women in engineering. At a time when we are actively recruiting women for engineering programs, however, it is important to consider all possible barriers to their success.

In our current educational setting, there is little guarantee that students begin their college studies with well-developed spatial skills. To remedy this, Michigan Tech has been offering a special course aimed at improving the 3-D spatial skills of students who have a demonstrated weakness in that area since 1993 [8]. The original spatial skills course was offered using a "traditional" lecture style with a textbook written specifically for the course.

In 2000, with funding from the National Science Foundation, the Michigan Tech team developed multimedia software and a workbook to replace the original textbook used in the spatial skills course. The software and workbook were thoroughly tested with first-year engineering students and were found to be user-friendly and just as effective in improving spatial skills as was the original textbook [9]. In research conducted in the fall of 2004, the software and workbook were tested with first-year students who were in non-engineering majors. In this study, it was determined that the materials could be used effectively with a non-engineering audience [10]. It was also determined that the software alone was not as effective as when used in conjunction with the workbook.

In order to demonstrate the appropriateness of the materials for use with a younger audience, research is currently being conducted with high school and middle school students. Before conducting this research, it was desired to pilot-test the materials with a younger audience to determine if they would need to be modified for use in a K-12 setting. The remainder of this paper describes the pilot study conducted in the spring of 2005 and presents the results of the study.

II. PILOT STUDY GROUP

The pilot school was a small secondary school in a rural setting. The district has a large population of at-risk and economically disadvantaged students, with 44% of the school's students qualifying for free or reduced lunch. However, the eighth grade state testing scores (MEAP) for the pilot school and for the subset of pilot study students were above the state average in all categories as shown in Table I.

Table I. Percent Passing in 8th Grade MEAP tests

	Pilot Group	Pilot School	State
Math	100%	84%	62%
Science	88%	73%	65%
Social Studies	63%	46%	30%

The eighth grade class at the pilot school consists of 37 students in total with a wide range of learning abilities. Students are required to take an Integrated Technology course that integrates the use of computers, graphing calculators, scientific probes, Geographic Information Systems (GIS), and Global Positioning Systems (GPS) with their core courses in science, mathematics, social studies, and English. Due to scheduling issues, the students in the pilot study group were honor roll students who were highly motivated, had strong math skills, and were highly organized. Of the 16 students in the pilot study, there were twelve females and four males.

III. GOALS OF THE PILOT STUDY

The main purpose of the pilot study was to determine if the materials that were initially developed for first-year engineering majors could be used effectively with eighth grade students as is, if modifications to the materials would be necessary for successful implementation, or if an entirely new approach is required for this audience. If the materials were found to be age-appropriate, then their effectiveness in improving 3-D spatial skills for this audience was desired. The instrument used in determining improvements in spatial skills was the Purdue Spatial Visualization Test: Rotations (PSVT:R) [11].

Additional objectives of the pilot study included observing the students as they worked through the materials to note their overall strengths and weaknesses with a middle school audience. Through these observations, a timeline was established for each module that is being used in the full-scale studies currently in progress. Gender differences were not examined as part of the pilot study due to the small sample size.

IV. METHODOLOGY

The spatial skill-building materials were implemented as a part of the Integrated Technology course at Jeffers High 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, of 54 minutes each, 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 work on the workbook pages. Enough classroom time was allowed for the students to complete a majority of the exercises in each module. The students were not required to complete all of the exercises, but were required to stay on task and work 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, similar to the blocks used by the Michigan Tech engineering students.

The students were asked to evaluate each module upon completion. The results from these attitudinal surveys are given in Tables II-V. In viewing the data in the tables, it should be noted that the modules were numbered according to the following scheme:

1. Isometric Pictorials
2. Multiview drawings/Orthographic Projection
3. Flat Patterns
4. Rotation of Objects about a Single Axis
5. Reflections and Symmetry
6. Cross-Sections of Solids
7. Surfaces and Solids of Revolution
8. Combining Objects

Table II. Responses to “How well did you understand the exercises this week?”

Module	1	2	3	4	5	6	7	8
Very Well	7	2	5	7	5	8	8	11
Well	8	12	10	10	10	9	8	4
Little			2			1		
Not at all		1				1		

Table III. Responses to “What helped you to understand the work this week?” (More than one response permitted)

Module	1	2	3	4	5	6	7	8
Workbook Examples	2	4	3	3	4	5	5	3
Software	7	7	8	14	10	16	14	13
Teacher	7	5	11	7	5	3	3	2
Other Students	8	10	11	10	10	13	13	10
Workbook Exercises	13	7	9	12	9	11	8	9
Blocks	12	13		13	2			
Nothing		1						

Table IV. Responses to “Which do you prefer working with?”

Module	1	2	3	4	5	6	7	8
Workbook	5	8	5	1	5	3	1	3
Computer	8	1	3	1	2	2	4	1
Both	10	8	9	14	10	12	11	11

Table V. Responses to “Did you have enough time to learn the materials this week?”

Module	1	2	3	4	5	6	7	8
More than enough	1	13	2	2	2	4	3	4
Enough	13	4	12	14	10	13	12	10
Needed More			3				2	1

In analyzing the data presented in these tables, some interesting observations can be made. The majority of the students felt that they understood the material (Table

II) and that they were given enough time to complete the exercises appropriately (Table V). Most students stated a preference for working with *both* the multimedia software and the workbook (Table IV). This is in contrast to a similar question asked of the 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 [10].

In examining the responses reported in Table III, it is interesting to note that working with other students was routinely selected as a choice for a feature that helped them understand the material. Based on the fact that 12 of the 16 students were female, this finding supports earlier work that indicates a strong preference for collaborative work among females [10]. The workbook exercises and the software received high marks for nearly every module. The blocks were used only for certain modules (1, 2, & 4), and they were rated highly for each of these sessions.

V. GAINS IN SPATIAL SKILLS

A modified version of the PSVT:R test was used as a pre- and post-test to measure improvements in spatial skills. The modifications made to the original test were: 1) the number of items was reduced from 30 to 14, 2) the number of choices on each item was reduced from five to three, and 3) a time limit was not imposed. The rationale for these changes was to make sure that the test was not overwhelming for the eighth grade students. All of the students completed the modified version of the test within about 10 minutes. Approximately two weeks after students took the modified post-test, they were given the original 30-item PSVT:R with five choices per item. Most were done in 20 minutes. All were done in 30 minutes.

Figure 1 shows the results from the pre- and post-testing. The line y=x indicates no change in the two scores—the students above the line showed an increase in their score, while those below the line showed a decline in their score.

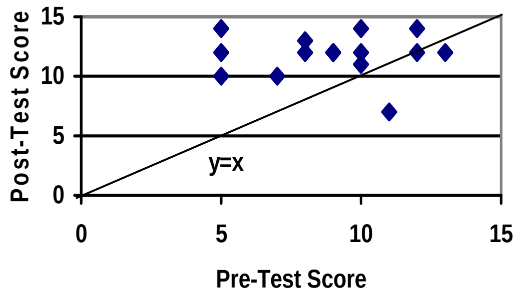

Figure 1. Scatter Plot of Pre- and Post-Test Scores

Table VI includes data from the pre- and post-testing in terms of means, medians, and standard deviations.

Table VI. Results from Pre- and Post-testing

	Pre-Test	Post-test
High Score	92.9%	100%
Low Score	35.7%	50.0%
Mean	63.6%	82.9%
Median	64.3%	85.7%
Std. Deviation	17.9%	12.1%

In performing statistical analysis on the data, the average gain was 20.5%. In performing a t-test, the average gain was determined to be statistically significant ($p<0.005$), even though the sample size was relatively small.

The mean post-test score on the unmodified version of the PSVT:R that students completed two weeks after the conclusion of the study was 74.7%--nearly 10% lower than the average score on the modified version of the instrument. However, it is unknown whether the pre-test mean would have also been lower by a similar amount. Further study of this is required.

VI. CONCLUSIONS

The results from the pilot study showed that the materials developed for Michigan Tech's first-year engineering students are suitable for use with a younger audience. Although the pilot study group was an above-average group of eighth graders, the course instructor, who has more than ten years teaching experience, believes that the materials are age-appropriate for all students of that grade level. The amount of time these students required to complete the exercises was typically longer than that required by the Michigan Tech students.

The results from this pilot test have been used to design the full-scale tests with middle and high school students currently underway. One of the most significant changes was the development of a new instrument for assessing spatial skills. This new instrument includes items from the PSVT:R, the Mental Cutting Test [12], the Differential Aptitude Test: Space Relations [13], and additional items covering isometric and orthographic sketches developed by the authors. This new instrument will be tested with control groups at both the middle school and high school levels for validity and comparison purposes.

VII. Acknowledgement

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