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Experiences in Using Spatial Skills Testing Instruments with Younger Audiences

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Abstract. As graphics educators, we routinely test the 3-D spatial skills of our university-aged students using standardized instruments such as the Purdue Spatial Visualization Test: Rotations (PSVT:R), the Mental Cutting Test (MCT), the Mental Rotation Test (MRT), and the Differential Aptitude Test: Space Relations (DAT:SR). These tests were developed and validated primarily with older subjects and have not been used significantly with younger audiences. At Michigan Technological University, we have been offering a course aimed at improving the 3-D spatial skills of our first-year engineering students since 1993, but with proper training at the pre-college level, the need for our course should be diminished. Spatial skills are a part of the national standards for K-12 math education in the US; however, most teachers have been hesitant to include spatial skills training in their pre-college mathematics courses due to a lack of suitable materials for that audience. Further, with the current emphasis on testing in the US, teachers will need to be able to show that spatial skills interventions improve test scores. As part of a research study funded by the National Science Foundation in the US focused on improving the 3-D spatial skills of middle school and high school students, who typically range from 13-years old to 17-years old, the standardized testing instruments were modified and tested with these audiences. This paper describes the types of modifications made to the testing instruments and details the results obtained from using them to assess 3-D spatial skills among younger students.

Key Words: 3-D spatial skills, pre-college education, testing instruments, gender differences

MSC: 51N05

1. Introduction

It is well documented that spatial skills are critical to success in engineering and technological careers. It is further well-established that the spatial skills of women typically lag behind

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those of their male counterparts, thus presenting women with a barrier to success in the male-dominated field of engineering. The author has been involved in teaching a course at Michigan Tech since 1993 aimed at improving the spatial skills of first-year engineering students. This course was developed with funding from the National Science Foundation and was the topic of a paper published in the Engineering Design Graphics Journal [9]. Long-term assessment results from this course have shown that engineering students who initially failed the Purdue Spatial Visualization Test: Rotations (PSVT:R) [4] and who subsequently enrolled in the spatial skills course went on to perform better in their engineering graphics courses by a significant margin [10]. Further, for women with initially weak spatial skills, participation in this course led to a significantly higher retention rate in engineering over a six year period when compared to women with weak skills who did not participate in the course [12].

According to Piaget [2], spatial skills are developed in three stages. In the first stage, topological skills are acquired. Topological skills are primarily two-dimensional and are acquired by most children by the age of 3–5. With these skills, children are able to recognize an object's closeness to others, its order in a group, and its isolation or enclosure by a larger environment. The second stage involves visualizing three-dimensional objects and perceiving what they will look like from different viewpoints or what they would look like if they were rotated or transformed in space. Most children have typically acquired this skill by adolescence, however, if the object is unfamiliar, many students in high school or even college have difficulty visualizing at this stage of development. In the third stage, people are able to visualize the concepts of area, volume, and distance in combination with those of translation, rotation, and reflection. At this stage, therefore, a person is able to combine measurement concepts with their previously acquired projective skills.

Many tests have been developed over the years to assess spatial skills in the first two stages of development. In engineering, we are primarily interested in 3-D spatial skills. Some of the primary tests used in educational research to assess 3-D spatial skills include the previously mentioned PSVT:R [4], the Differential Aptitude Test: Space Relations (DAT:SR) [1], and the Mental Cutting Test (MCT) [3]. Example problems from each of these tests are shown in Figs. 1–3.

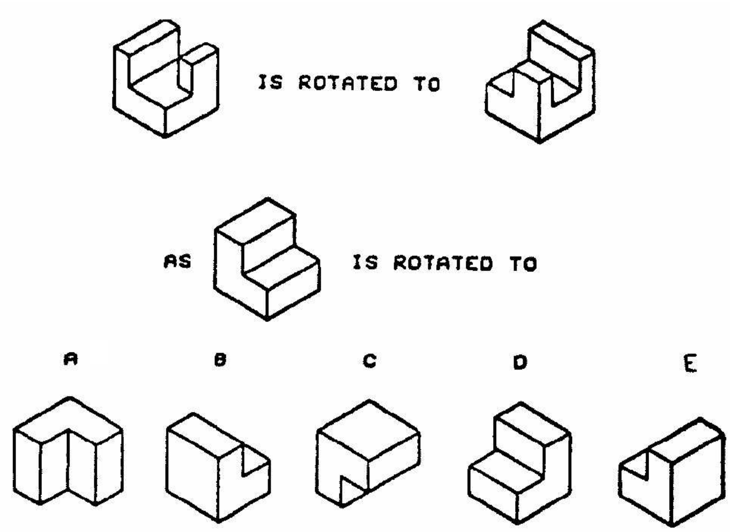

Figure 1: Sample problem from PSVR:T

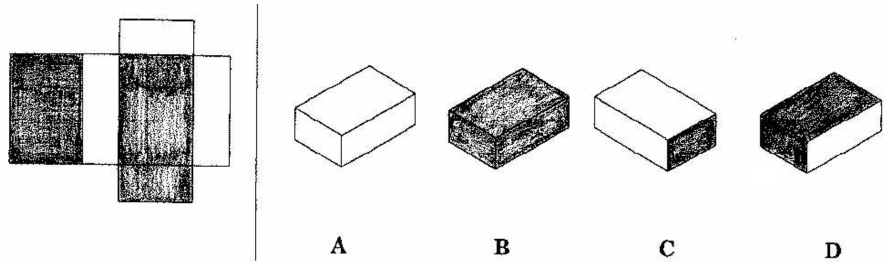

Figure 2: Sample problem from DAT:SR

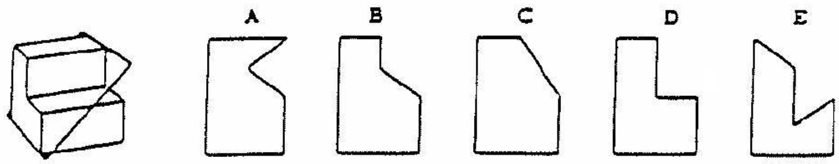

Figure 3: Sample problem from MCT

Most of these tests have been used in studies with students who are ∼16-year old or older. In this study, we developed a four-part test with components from these tests and from another and used them with groups of students in the 8^{th} and 11^{th} grade-ages of ∼13 and ∼17 years-old. The remainder of this paper describes the test and the results we achieved.

2. New testing instrument

Previously, a pilot study was conducted with middle school students in the spring of 2005 [8] to determine if the multimedia software and workbook developed for first-year engineering students was suitable for use with younger audiences. A modified version of the PSVT:R was administered as a pre-/post-test for the pilot study. Statistically significant gains on the PSVT:R were observed for the pilot group students; however, it was noted that the PSVT:R test only measures a person's ability in one component skill of 3-D spatial visualization–rotation of objects. A new test was formulated, drawing on problems from three different 3-D spatial skills tests as well as the modification of items from a fourth spatial skills test. The four types of problems included in this newly devised test were designed to assess four different components of 3-D spatial visualization. Each section of the test consisted of 10 problems, meaning that the new test consisted of 40 problems in total. The procedure used to develop the test and the rationale used in selecting/designing problems is described in the following paragraphs.

The first set of problems on the test consisted of items from the PSVT:R. When selecting the problems for inclusion, care was taken to insure that they were of variable difficulty. Since the original PSVT:R consists of 30 questions that are increasingly difficult from start to finish, items for the new test were selected from the first third (items 1–10), the middle third (items 11–20), and the final third (items 21–30) in roughly equal proportions.

The second set of 10 problems on the test were taken from the MCT; the third set of 10 problems were taken from the DAT:SR. Problems for inclusion were selected using the same process described as that for the PSVT:R. For each type roughly one-third were considered to be easy, one-third were of medium difficulty, and one-third were difficult.

The final set of 10 problems for the new test consisted of modified problems from a test developed by LAPPAN for use with students in grades 5–8 [6]. These problems were designed to determine whether or not students understood the basics in making isometric pictorials and the relationship between pictorials and multiview drawings. In the original test by LAPPAN, the problems were not set up in a manner consistent with the conventions included in the multimedia software and workbook. The software and workbook were based on conventions in engineering sketching; the problems on the LAPPAN test were based on conventions in mathematics instruction. For example, on the LAPPAN test, isometric pictorials of objects include all of the lines defining the individual blocks that comprise it; whereas, by engineering convention, lines are only shown where two surfaces intersect to form an edge. Fig. 4 shows an item from the LAPPAN test dealing with isometric pictorials and Fig. 5 shows the item included on the test in its modified format so that the conventions described in the multimedia software were maintained.

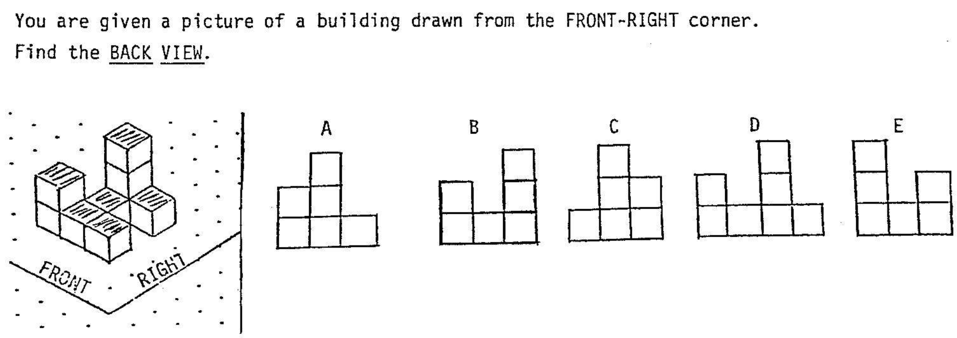

Figure 4: Original isometric test item

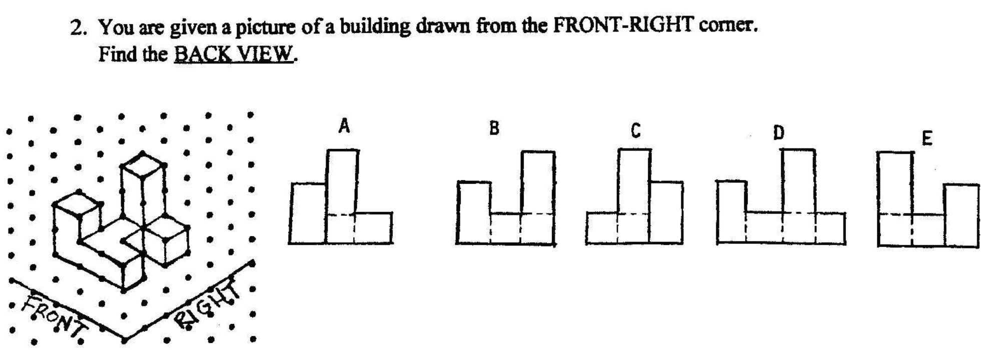

Figure 5: Modified isometric test item

Another area where the items on the LAPPAN test did not match the conventions described in the software and workbook was in the placement of views. In LAPPAN's test, the three views of an object are placed all in a single row; whereas, according to engineering convention the three views of an object must project orthographically to form an L-pattern. Fig. 6 shows an original item from the LAPPAN test and Fig. 7 shows the modified version used on our new test.

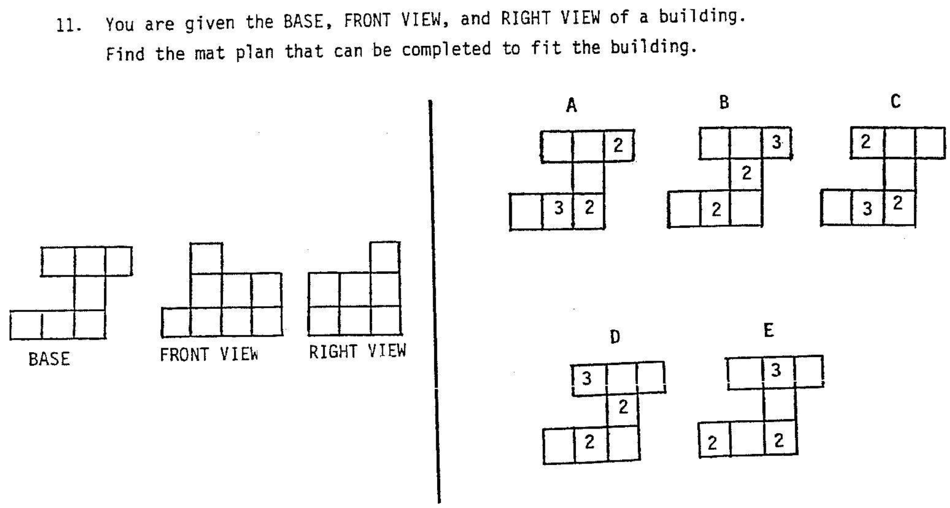

Figure 6: Original multiview test item

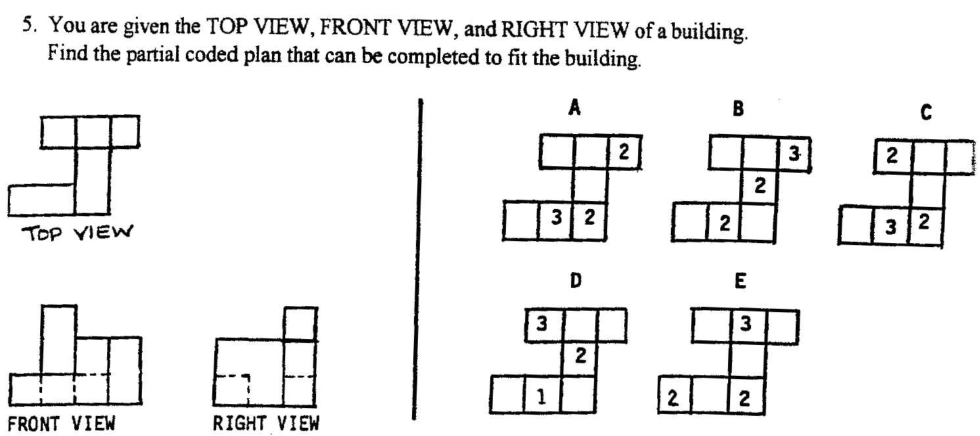

Figure 7: Modified multiview test item

2.1. Test administration

The new test was administered to students in the 8th and 11th grades in the Houghton-Portage Township School district in the Fall of 2005. The students were given the test such that they had time between sections to learn about the new problem types, view appropriate examples, and ask questions as needed. The test was administered at the beginning of the semester as a pre-test and then towards the end of the semester as a post-test to determine the magnitude of any practice effect. Table 1 gives the demographics of the students taking the test.

In the first part of the analysis, we used two factor multivariate analysis-of-variance to

	8th grade	11th grade
Male	$n = 38$	$n = 25$
Female	$n = 43$	$n = 23$

Table 1: Student demographics (sample sizes)

determine if there were differences in mean scores for the four test component scores by grade and/or gender. We found significant gender ($p = 0.0072$) and grade ($p = 0.0001$) effects, but the gender by grade interaction was not significant ($p = 0.1504$). Thus we constructed marginal tables of means by gender and grade level. Table 2 gives the average pre-test scores for each component of the test by grade level as well as the p-value for the univariate ANOVA test of the difference between the means. Table 3 gives corresponding results by gender.

Grade	Rotation	Cutting	Folding	Isometric
8^{th}	48.9%	26.3%	48.5%	30.3%
11^{th}	59.0%	36.3%	73.3%	60.6%
Sig. of difference	$p = 0.0166$	$p = 0.001$	$p < 0.0001$	$p < 0.0001$

Table 2: Mean pre-test scores by grade level (p-values from ANOVA)

Gender	Rotation	Cutting	Folding	Isometric
Male	59.7%	34.7%	62.1%	51.2%
Female	48.3%	27.9%	59.7%	39.8%
Sig. of Difference	$p = 0.0069$	$p = 0.0226$	N.S.	$p = 0.0032$

Table 3: Mean pre-test scores by gender (p-values from ANOVA)

From Tables 2 and 3, it is apparent that there are significant differences in mean scores by gender and by grade level for virtually all components (except there were no significant gender differences on the folding component of the test). Component scores were higher for 11^{th} grade students when compared to 8^{th} grade students indicating that spatial skills improve as a student advances through the K-12 curriculum. By grade level, the largest increases were in the folding and isometric components of the spatial skills test, with increases of ~24% and 30%, respectively. The rotation and cutting components increased by only ~10% each. In research conducted by Sorby [11] and by Hamlin, Boersma, and Sorby [5], the rotation and cutting components of spatial skills were found to be the most important for success in learning to use engineering computer aided design software. Maier [7] also found that a person's mental rotation ability was the most important spatial skill for success in technical fields. Thus, it appears that our K-12 students' 3-D spatial skills improve as they progress through the curriculum; however, improvements in the two component skills necessary for success in technical fields such as engineering are not as large as improvements in other components of spatial skills.

2.2. Test component correlations

Correlations between test components were computed to determine if there is a "spatial" intelligence that is underlying the component skills measured by the various testing instruments. Table 4 includes data from this analysis.

Correlations among the test scores for the four test components were generally strong Table 4). We tested for differences in correlation matrices across gender and grade combi-

	Rotation	Cutting	Folding	Isometric
Rotation	1.00	0.3782 $p < 0.0001$	0.4725 $p < 0.0001$	0.5250 $p < 0.0001$
Cutting	0.3782 $p < 0.0001$	1.00	0.3637 $p < 0.0001$	0.4596 $p < 0.0001$
Folding	0.4725 $p < 0.0001$	0.3637 $p < 0.0001$	1.00	0.6239 $p < 0.0001$
Isometric	0.5250 $p < 0.0001$	0.4596 $p < 0.0001$	0.6239 $p < 0.0001$	1.00

Table 4: Correlation matrix for spatial skills components
(data pooled across grade and gender; $n = 129$)

nations but found no significant differences ($p = 0.62$) so correlations were computed from data pooled across gender and grade. These strong correlations could support the notion that there exists an overall "spatial ability" that transcends the individual component skills.

The highest degree of correlation was found between the folding and isometric components – the two components that seem to be addressed the most effectively in our K-12 system.

2.3. Test component gains

Average gain scores between the pre-test at the beginning of the semester and the post-test at the end of the semester were computed for each component to determine if there is a "practice effect" apparent for students who take the test more than one time. Table 5 includes data from this analysis.

We compared mean gains between genders and grades using a two-way multivariate ANOVA, but found no significant gender or grade effects (gender $p = 0.2801$; grade $p = 0.1851$; interaction $p = 0.3607$). We therefore pooled data across genders and grades to estimate mean gains (Table 5). It should be noted that for this group of students, there was no formal intervention occurring between the administration of the pre- and post-tests.

The data in Table 5 indicates that there may be a slight improvement in test scores based on the practice effect on the rotation component. There appears to be a significant practice effect for the isometric component of the spatial skills test. Given the large gains on the isometric component by grade level, however, the gains on this portion of the test could in part be due to time spent in classes between the pre- and post-test.

	Rotation	Cutting	Folding	Isometric
Avg. pre-test	52.7%	30.0%	57.7%	41.7%
Avg. post-test	56.4%	32.2%	55.0%	47.1%
Avg. gain	3.7%	2.2%	-2.7%	5.4%
Sig. of gain	$p = 0.0922$	$p = 0.2235$	$p = 0.2255$	$p = 0.0022$

Table 5: Gain scores on spatial skill components
(data pooled across gender and grade; $n = 129$)

3. Conclusions

A new test was designed that included questions from four different component spatial skills. This instrument was tested with students in the 8^{th} and 11^{th} grades. It was found that there is a significant amount of correlation between spatial skill components, implying that there is an underlying spatial ability. Students did not experience any formal training in spatial skills development between the pre- and the post-test. Student gains on most of the components were small indicating that the "practice effect" is minimal. The exception to this was in the isometric component of the test where gains were significant ($p = 0.0022$). However, the gains on the isometric component could be due to the natural development of this type of spatial skill as a student progresses through the K-12 curriculum. Future plans include administering the new test to a large number of students in the middle and high school grades to test for validity and repeatability.

Acknowledgements

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