Spatial Visualization Skills at Various Educational Levels

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Abstract

Spatial visualization skills are important in engineering graphics and computer-aided design courses, especially in solid modeling, which has gained popularity in recent years. Some research has been done to investigate if visualization skills can be improved through training. The research typically compares the pretest and posttest scores of students taking a graphics or computer-aided design course. However, results usually were not conclusive. This paper presents a comprehensive study on spatial visualization skills at various educational levels. The Purdue Spatial Visualization Test – Rotation was given to high school students, college students at different levels, and high school teachers. The spatial visualization skills among different educational levels were compared. Other possible factors, such as age and gender, were also investigated. Statistical analyses of the data revealed the effects of long term training and general education on the improvement of visualization skills.

1. Introduction

The ability to visualize spatially is generally considered fundamental for graphics apprehension, especially three-dimensional (3D) solid modeling using computer-aided design (CAD) software packages. Thus, it is important to determine the answer to the question: Does training improve spatial visualization ability? Research has not been able to draw a definitive conclusion. Some studies [3, 15, 19] showed that graphics training did improve spatial visualization ability, while other studies [7, 13, 14, 17, 18] showed no evidence of such improvement. The results of some recent studies [17, 18] showed that even though there were no significant differences between average scores on a spatial visualization test, students from higher level classes indeed scored better than those in lower level classes. In light of these results, this study focused on the long-term effects of education and training on spatial visualization abilities by comparing performance at various educational levels. This study also investigated other factors which may affect spatial visualization abilities, such as graphics grades, age, and gender, using larger sample sizes than previous studies.

2. The Spatial Visualization Test

Various tests have been developed to measure different types and levels of spatial visualization ability [1]. Among these tests, the Purdue Spatial Visualization Test – Rotation (PSVT-R) [9] has been widely used by researchers. This study also chose the PSVT-R to measure spatial visualization ability. The PSVT-R was designed to test rotational visualization ability. It consists of 30 multiple-choice problems. In each problem, an example first shows an object in its original and rotated views in isometric drawing. Then another object is shown in five different rotations, and the student is to choose the rotation that matches the given example. A sample problem similar to that of the PSVT-R is shown in Figure 1.

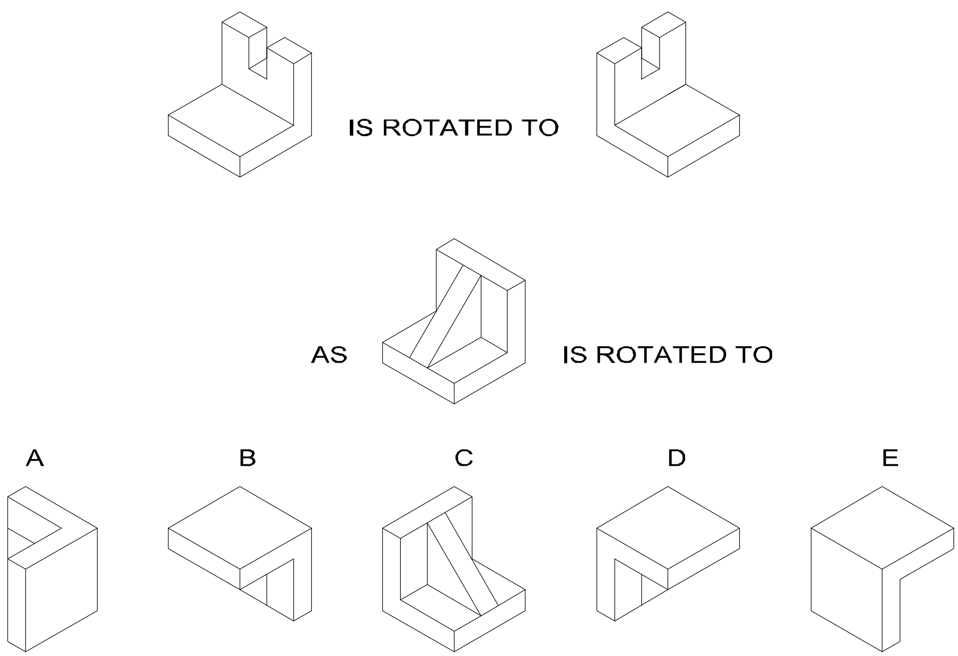

Figure 1. Example of a Rotational Spatial Visualization Problem

All of the 3D objects in the PSVT-R test consist of simple geometric shapes of either a cube or a cylinder with cut slots. The transformations are combinations of 90° and 180° rotations about the axes of the Cartesian coordinate system. The problems in the PSVT-R test can be categorized into four types according to their patterns and difficulties of rotation. These four types are: a 90° rotation about one axis, a 180° rotation about one axis, a 90° rotation about an axis and another

90° rotation about another axis, and a 180° rotation about an axis and a 90° rotation about another axis. The degrees of difficulty of rotation increase from type I through type IV, and are also quite evenly distributed on the test (six problems in type I and eight problems each for types II through IV.) Logically, the more difficult the rotations are, the harder the visualization would be. Yue's study [17] of 64 students in engineering graphics and CAD classes showed that there were significant differences among the mean PSVT-R test scores for the four types of rotations [$F(3, 252) = 11.38$, $p < .01$]. Further analysis using Scheffe's method showed that the mean score differences are significant between types I and II and between types I and IV, but not for other pairs. Therefore, the simplest single 90° rotation is easier to visualize than other more difficult types of rotations, but the mean score differences for the more difficult rotations are not statistically significant. Further research is needed to design and improve standardized spatial visualization tests.

3. Test Samples

Essex County College (ECC) is a two-year urban community college located in the downtown of Newark, the largest city in New Jersey. The student population of ECC has a high percentage of minorities including 51% of African Americans and 17% of Hispanics. Since fall 1999, the students in various classes at ECC have taken the PSVT-R test. Students in the courses *ENR 103, ENR 105, and ENR 205* (Table 1), as well as high school teachers in a CAD training class were used as samples in this study. *ENR 103* is required for all engineering and technology majors including Architectural Technology, Civil Construction Engineering Technology and Land Surveying, CAD Technology, Electronic Engineering Technology, Engineering, and Manufacturing and Mechanical Engineering Technology. *ENR 105* is required for all of the engineering and technology majors except for the Electronic Engineering Technology major. *ENR 205* is required only for the Architectural Technology degree and CAD Technology certificates. The prerequisite for the entry-level course *ENR 103* is *MTH 092/093 Elementary Algebra (4.5 credits)*, a developmental course to prepare students for college-level mathematics courses.

Table 1. Sequence of Engineering Graphics and CAD Courses [22]

Course	Title	Credits (Contact Hours)	Prerequisites
ENR 103	Engineering Graphics	2 (3)	MTH 092/093
ENR 105	Applied CAD	2 (3)	ENR 103
ENR 205	Advanced CAD	3 (3)	ENR 105

There were five groups of students included in this study. Other than the regular students taking the sequence of *ENR 103*, *ENR 105*, and *ENR 205*, there were a group of 12 high school students from the Essex County Vocational Schools and a group of 18 high school teachers from about a dozen of the Newark Public Schools. The high school students were seniors taking the *ENR 105* course under a scholarship to earn college credits, and had been given CAD training in high school. The high school teachers took an enhanced one-semester CAD training course, comparable to *ENR 105*, to prepare them for teaching CAD at their schools. These were mathematics, science, and technology teachers who had at least baccalaureate degrees (a long time ago), but some of them did not have prior engineering graphics or CAD experience. These five groups represent educational levels of high school seniors, college freshmen in their first and second semesters, college sophomores, and high school teachers or college graduates. The test samples of different educational levels are listed in Table 2.

Table 2. Test Samples of Different Educational Levels

Group Number	Group by Educational Levels	Sample Size
1	High School Seniors (HSS)	12
2	College Freshmen, First Semester (ENR 103)	85
3	College Freshmen, Second Semester (ENR 105)	47
4	College sophomores (ENR 205)	17
5	High School Teachers (HST)	18

The PSVT-R test was given in the classroom at the beginning of each semester. Several students took the PSVT-R test more than once in the sequence of *ENR 103, ENR 105, and ENR 205*. Only first-time test scores were used in the study to eliminate any possible retest effects.

4. Test Results

4.1. Comparison of PSVT-R Scores among Groups of Different Educational Levels

Mean PSVT-R test scores grew steadily higher with increasing educational level (Figure 2), except for the group of high school teachers. Many of these high school teachers had not had the chance to experience either engineering graphics or CAD for years, which might contribute to their unfamiliarity with spatial visualization. The mean PSVT-R test score from a senior solid modeling CAD class at Central Michigan University (CMU) [18] is also shown in Figure 2 for comparison purposes. The CMU samples consisted of 24 students in the class *IET 457 CAD* (3 semester credits and 4 contact hours) and the mean score was 24.96 (83%).

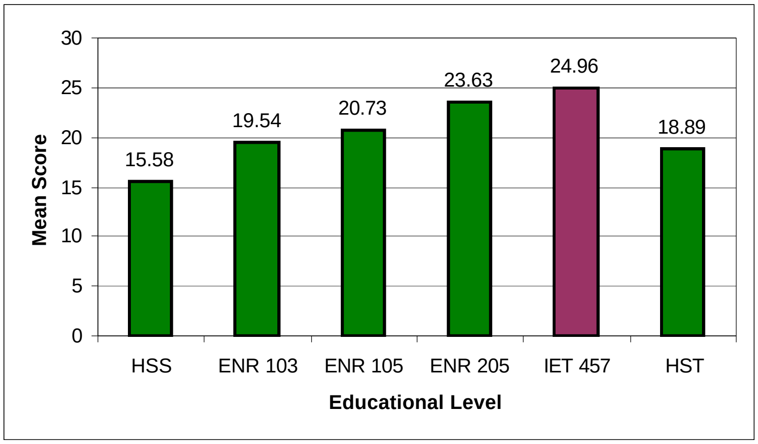

Figure 2. Mean PSVT-R Test Scores at Different Educational Levels

To investigate the statistical relationship among the group mean scores, the one-way analysis of variance (ANOVA) was applied to the 179 test samples. The differences among the mean scores were statistically significant [$F(4, 174) = 3.28$, $p < .05$], but not at a .01 level of significance. Scheffe's test was used to further investigate the relationship between each pair of groups. The results are shown in Table 3, where the Scheffe's critical values are at a .05 level of significance and X_i is the mean score for group *i* as defined in Table 2.

Table 3. Relationship between Pairs of Different Educational Levels

Mean Score Difference	Observed Value	Scheffe's Critical Value
$X_2 – X_1$	3.84	6.35
$X_3 – X_1$	4.82	6.66
$X_3 – X_2$	0.98	3.74
$X_4 – X_1$	8.53	7.76
$X_4 – X_2$	4.69	5.47
$X_4 – X_3$	3.71	5.82
$X_5 – X_1$	3.31	7.67
$X_5 – X_2$	-0.54	-5.34
$X_5 – X_3$	-1.52	-5.70
$X_5 – X_4$	-5.23	-6.96

From the results in Table 3, only the mean score difference between groups 1 and 4 (high school seniors and college sophomores) was statistically significant. The mean score differences between all other pairs were not statistically significant. This means that education, even directly related engineering graphics and CAD training, may not significantly improve spatial visualization skills, at least not in the short term. This result confirmed research by Yue and Chen [18]. In their study, the PSVT-R test was conducted at the beginning and end of CAD classes and showed no significant difference between the pre-test and post-test scores for student groups from both ECC and CMU.

4.2. Relationship between Spatial Visualization Abilities and Course Grades

The grades at ECC are A (4.0), B+ (3.5), B (3.0), C+ (2.5), C (2.0), D (1.0), and F (0.0). Students who withdrew from the classes were not included in the investigation of the relationship between spatial visualization abilities and course grades. The training class for high school teachers did not give grades, so they were also not included.

The mean scores on the PSVT-R test and course grades for all of the classes except the training class for high school teachers were 21.00 (70%) and 2.74 (69%) respectively. The mean score difference is not statistically significant [$t(135) = 1.59$, $p > .05$].

Analyses of individual groups give the following results. The mean scores on the PSVT-R test and *ENR 103* grades were 20.80 (69%) and 2.86 (72%) respectively. Their correlation coefficient was 0.28, which is statistically significant at a .05 level of significance [$t(67) = 2.34$, $p < .05$], but not at a .01 level of significance. The mean scores on the PSVT-R test and *ENR 105* grades of the high school students were 16.50 (55%) and 2.80 (70%) respectively. Their correlation coefficient is 0.05, which is not statistically significant [$t(8) = 0.14$, $p > .05$]. The mean scores on the PSVT-R test and *ENR 105* grades of the college students were 21.09 (70%) and 2.87 (72%) respectively. Their correlation coefficient is -0.016, which is also not statistically significant [$t(41) = -0.10$, $p > .05$]. The mean scores on the PSVT-R test and *ENR 205* grades were 24.33 (81%) and 2.70 (68%) respectively. Their correlation coefficient is 0.27, which is again not statistically significant [$t(13) = 1.02$, $p > .05$].

The results did not show a relationship between spatial visualization abilities and CAD grades, as well as the overall course grades. This confirms one previous study with smaller sample sizes [18]. There may be a relationship between spatial visualization skills and engineering graphics grades, but not a strong relationship.

Different from standardized tests, many factors could affect the course grade of a student. Missing classes and assignments, variations in tests and examinations, and many other factors all contribute to grading. Nevertheless, statistical analysis might still show some general trends.

4.3. Spatial Visualization Ability by Gender

The overall mean scores of the 34 female students and 145 male students of the five groups were 16.76 (56%) and 20.53 (68%) respectively. The mean score of the male students is statistically higher than that of the female students [$t(177) = 2.98$, $p < .01$].

A detailed comparison of the PSVT-R test scores by the male and female students in each group is as follows. The mean scores on the PSVT-R test for the 6 female and 6 male high school students were 14.17 (47%) and 17.00 (57%) respectively. The mean score difference is not statistically significant [$t(10) = 0.83$, $p > .05$]. The mean scores on the PSVT-R test for the 14 female and 71 male college freshmen in the *ENR 103* classes were 18.36 (61%) and 19.63 (65%) respectively. The mean score difference is also not statistically significant [$t(83) = 0.61$, $p > .05$]. The mean scores on the PSVT-R test for the 11 female and 36 male college freshmen in the *ENR 105* classes were 16.82 (56%) and 21.50 (72%) respectively. The mean score of the male students is statistically higher than that of the female students [$t(45) = 2.34$, $p < .05$], but not at a .01 level of significance. There were only two female students in the *ENR 205* classes and one female high school teacher. The small numbers did not permit meaningful comparisons by gender. The mean scores of the male students were higher than that of the female students in all three levels, but only the mean score difference in the *ENR 105* classes was statistically slightly significant.

4.4. Spatial Visualization Ability by Age

The students in each group were divided into two subgroups: one younger than 23 years of age and the other 23 years of age or older. Students who did not reveal their ages were not included in this analysis.

The mean scores on the PSVT-R test for the 49 younger and 32 older college freshmen in the *ENR 103* classes were 20.41 (68%) and 18.31 (61%) respectively. The mean score difference is not statistically significant [$t(79) = -1.26$, $p > .05$]. The mean scores on the PSVT-R test for the 24 younger and 23 older college freshmen in the *ENR 105* classes were 20.38 (68%) and 20.43 (68%) respectively. The mean score difference is also not statistically significant [$t(45) = 0.03$, $p > .05$]. The mean scores on the PSVT-R test for the 9 younger and 8 older college freshmen in the *ENR 205* classes were 23.00 (77%) and 25.38 (85%) respectively. The mean score difference is again not statistically significant [$t(15) = 1.10$, $p > .05$]. The high school students were all younger than 23 years and the high school teachers all were older than 23 years, so those groups could not be analyzed by age.

Combining the five groups, the overall mean scores for the 94 younger students and 81 older students were 20.03 (67%) and 19.74 (66%) respectively. The mean score difference is not statistically significant [$t(173) = -0.290$, $p > .05$].

Thus, this study showed that age might not be a factor in spatial visualization abilities.

5. Conclusion

This study on spatial visualization has two unique features that are different from many other studies on this topic. First, the research was conducted at an urban two-year community college with a high percentage of minority students, a population that was different from other survey samples. Second, the research investigated and compared the scores on a spatial visualization test by students of different educational levels. The test samples consisted of five groups at different educational levels including high school students, college freshmen and sophomores taking a sequence of three engineering graphics and CAD courses, and high school teachers. The results showed that the scores on the PSVT-R test increased steadily with higher educational level (except for the high school teachers), but also that the mean score differences among the groups were not statistically significant, except between the high school seniors and the college sophomores. There was no significant correlation between the PSVT-R test scores and CAD course grades, and only a slight correlation of the PSVT-R test scores and engineering graphics course grades. The mean score on the PSVT-R test for male students was statistically slightly higher than that of the female students in the freshman CAD classes, but there was no significant difference between the mean scores by gender in the engineering graphics and sophomore CAD classes. There was no significant difference between the mean scores on the PSVT-R test of the two age groups of the college students.

Spatial visualization abilities may involve comprehensive factors and may be developed in some informal ways, such as childhood play with construction toys, sketching and drafting experiences, computer and video games, sports activities, and real-life experience with 3D objects. Quick improvement of spatial visualization skills through short-term training was not obvious, but it might be improved through long-term education and training. More research is needed to find the relationships between spatial visualization abilities and other possible factors.

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