Spatial Visualization by Realistic 3D Views

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Abstract

In this study, the popular Purdue Spatial Visualization Test – Visualization by Rotations (PSVT-R) in isometric drawings was recreated with CAD software that allows 3D solid modeling and rendering to provide more realistic pictorial views. Both the original and the modified PSVT-R tests were given to students and their scores on the two tests were compared to investigate whether there was improvement in performance on spatial visualization tests with realistic 3D views. The study involved 157 first year community college students in engineering and technology majors and 34 high school seniors from a technical careers high school, all of whom were taking an engineering graphics course or a CAD course at the college when taking the tests. The test scores were analyzed in four groups: graphics classes, CAD classes, high school students, and a comparison group. In all four groups, the mean scores of the realistic 3D test were higher than the mean scores of the isometric test, which shows enhanced performance on the spatial visualization test with realistic 3D views.

INTRODUCTION

Spatial visualization is a fundamental skill in engineering and technology fields. From the traditional board drawings of multiviews, sections, and assemblies, to modern solid modeling using computer aided design (CAD) software, almost all product designs require the visualization of three-dimensional (3D) objects. Spatial visualization abilities have become more important in new technological frontiers such as space exploration, remote robotic surgery, etc.

In recent decades, educators and researchers have developed various test formats to evaluate students' spatial visualization skills. In the 1970s, psychologists intensively studied spatial visualization from the perspective of cognition and perception. Shepard and Metzler (1971) designed a test to investigate the reaction time of visualizing rotated 3D objects. Vandenberg and Kuse (1978) later developed a test, based on Shepard and Metzler's model, known as the mental rotation test (MRT). Ekstrom, French, and Harman (1976) also included spatial visualization in a set of cognitive tests, which were included in the Educational Testing Service's (ETS) catalog of standardized tests. Engineering and technology educators also investigated the relationship between spatial visualization abilities and technical graphics skills. Among these educators, Guay (1976) developed the Purdue Spatial Visualization Test (PSVT) which consists of 36 questions equally divided into three categories: developments, rotations, and isometric views. Guay (1977) also expanded the questions of rotations into a 30-question test called the Purdue Spatial Visualization Test - Visualization of Rotations (PSVT-R). The PSVT-R was included in the ETS test collection and has since been widely used by researchers in engineering and technology fields.

Since the 1980s, along with the development of microcomputers, CAD was introduced into classrooms. Since then, both computer hardware and software have been significantly improved, such that 3D solid modeling CAD has become ubiquitous in industrial applications. Therefore, spatial visualization has become a required skill for engineering and technology students. These developments have revitalized educators' interest in spatial visualization (Miller, 1996; Miller & Bertoline, 1991). Many engineering and technology educators have administered the PSVT-R test to thousands of students at a number of colleges and universities to evaluate their spatial visualization ability (Ardebili, 2006; Battista, 1981; Branoff, 1998a, b; Branoff & Connolly, 1999; Brus, Zhao & Jessop, 2004; Czapka, Moeinszdeh & Leake, 2002; Guay, 1978 March, 1978 June, 1980; Guay & McDaniel, 1978; Hamlin, Boersma, & Sorby, 2006; Kinsey, Towle, Hwang, O'Brien, & Bauer, 2006; Sorby, 1999, 2001; Sorby & Baartmans, 1996; Study, 2004, 2006; Towle et al., 2005; Yue, 2000, 2002a, b; Yue & Chen, 2001). A computerized version of the PSVT-R test, featuring additional references, such as Cartesian coordinate axes, has also been used (Branoff, 1998a, b; Branoff & Connolly, 1999). Other variations of the test formats for spatial visualization have also been attempted (Sorby, 2003; Sorby, Manner & Baartmans, 1998). Recently, educators have begun to use CAD software to create solid models in spatial visualization tests for more realistic 3D views (Ardebili, 2006; Kinsey et al., 2006; Sorby, 2003). However, axonometric drawing, predominantly isometric drawing, is still the dominant format of 3D views in spatial visualization tests.

Nowadays, solid modeling software has been widely adopted in engineering and technology curricula, and taught to college students. In contrast to the traditional engineering graphics courses in which students start with instrumental board drawings of multiviews or orthogonal projections of objects, students use CAD software to build a solid model first and automatically generate its multiviews with dimensions. Solid models show more realistic views of 3D objects that we see in our daily life. Therefore, many students feel solid models are easier to visualize than multiviews, especially for non-engineering majors who do not have training in orthographic drawings. Worst of all, isometric drawing is the simplest approximation of the view of a 3D object. Due to its oversimplifications and distortions in representing a realistic 3D view, tests created by isometric drawing may not be ideal instruments to evaluate students' spatial visualization ability.

To investigate the impact of replacing isometric drawings with more realistic 3D views in spatial visualization tests, the author chose to use the popular PSVT-R test. By recreating the objects in the PSVT-R test into 3D solid models and rendering them into more realistic pictorial views, the author compared the results of the original isometric test and the modified, more realistic 3D test to determine whether an improvement is shown in students' assessed visualization abilities.

THE ORIGINAL PSVT-R SPATIAL VISUALIZATION TEST WITH ISOMETRIC VIEWS

The PSVT-R test (Guay, 1977) is a popular spatial visualization test in engineering schools. This may be partly due to the fact that pictorial views were created in the test using isometric drawing, a simple orthogonal projection taught in engineering graphics courses. In each question, an example shows an object in its initial and rotated views. Then another object, along with its five different rotated views, is shown, and the student is to choose one rotated view that has resulted from the same rotation as the given model. As an example, the question #14 of the original PSVT-R test is shown in Figure 1.

THE MODIFIED PSVT-R SPATIAL VISUALIZATION TEST WITH REALISTIC 3D VIEWS

The objects in the PSVT-R test were recreated as 3D solid models and rendered using AutoCAD (2006) software to produce realistic pictorial views. Figure 2 shows an example of the rendered realistic 3D views of the same objects as shown before (Figure 1) for comparison.

A realistic pictorial view of a 3D object is composed of many necessary features. These

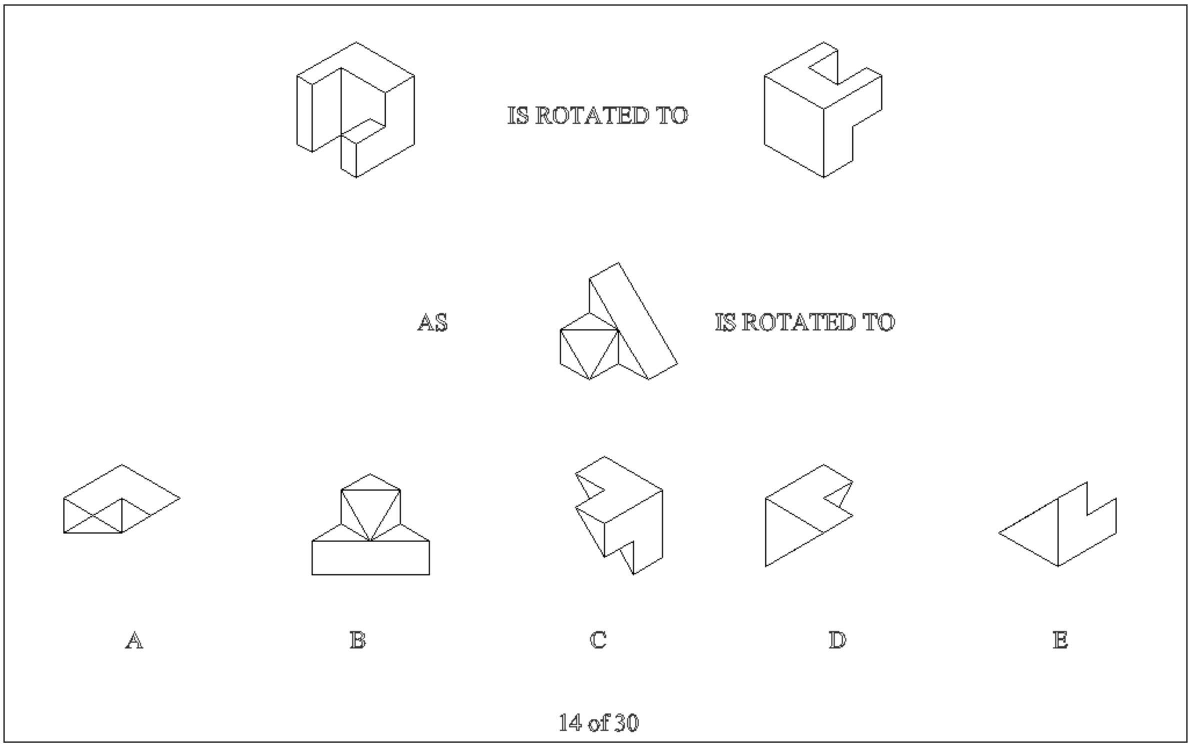

Figure 1: *Original views of the question #14 in the PSVT-R test (Guay, 1977)*

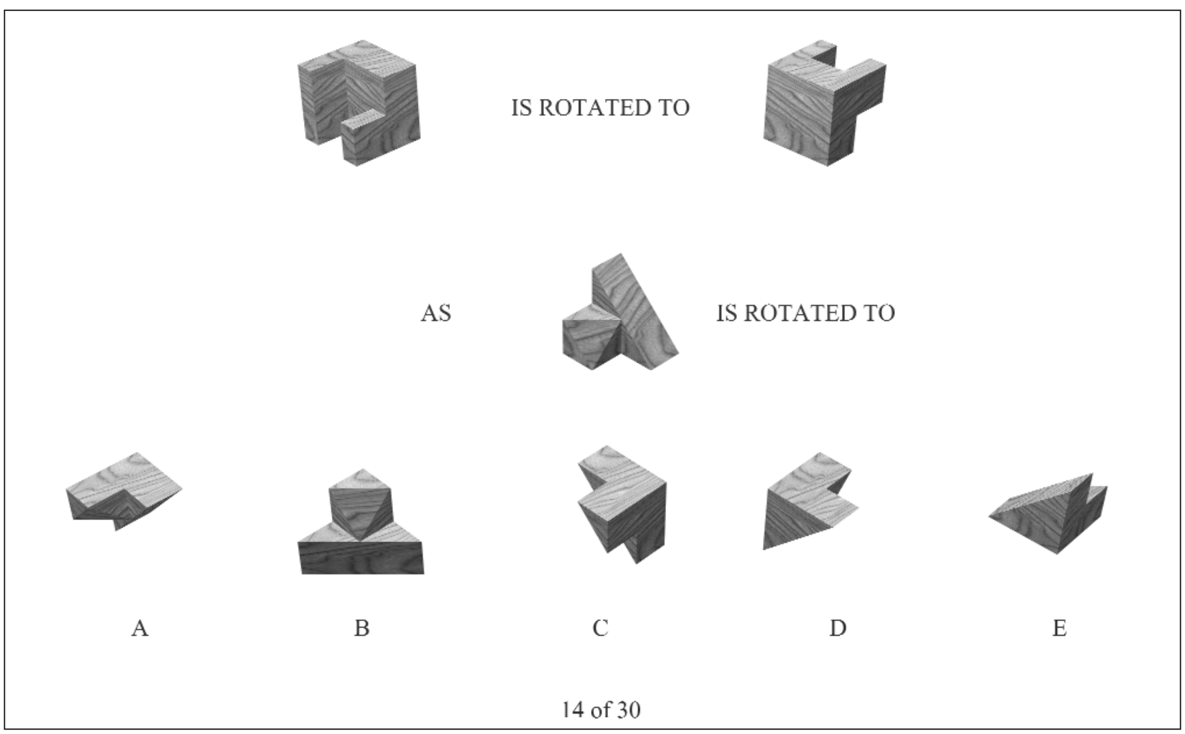

Figure 2: *Realistic 3D views with perspective effect*

features include 3D volume and dimensions, colors, external lighting and shades, light transmission, surface textures, material, perspective view, etc. Some settings for creating the 3D features in the modified test are listed in Table 1.

Table 1: *Feature settings in the modified PSVT-R test with realistic 3D views*

3D feature	Setting
Lights	Ambient light: intensity = 0.75 Point light 1: intensity = 5, position = (-10, 0, 10) Point light 2: intensity = 10, position = (10, -10, 10) Point light 3: intensity = 5, position = (0, 0, 10)
Perspective	Default
Material/surface texture	Solid wood medium ash

DISCUSSION OF THE ORIGINAL ISOMETRIC AND MODIFIED REALISTIC 3D PSVT-R TESTS

ISOMETRIC DRAWING IS PRONE TO ERRORS

An isometric drawing is easy to sketch in terms of its simplicity. However, due to its oversimplifications and distortions, isometric drawing is far from the true pictorial view of a 3D object. Isometric drawing, sketched on a 2D plane, is also prone to errors. For example, in the widely used original PSVT-R test (Guay, 1977), the isometric drawings in 7 out of the 30 test questions contain errors (23% error rate question wise). There were a total of 10 rotated views that contain errors. In question #13, 3 out of the 6 rotated views contain errors, including the example rotation. These errors include missing features, misrepresented features, and the inclusion of extra features as listed in Table 2 (Yue, 2007).

Table 2: *Summary of errors in the original PSVT-R test*

Item	Question Number	Drawing Number	Error
1	8 *	Example Rotation	Missing Features
2	10*	Example Rotation	Missing Features
3	13	Example Rotation	Missing Features
4	13	A	Extra Features
5	13	D	Missing Features
6	14	A	Missing Features
7	14	E	Missing Features
8	15	C	Extra Features
9	17	Example Rotation	Missing Features
10	25	B	Misrepresented Feature

** Questions #8 and #10 share the same exemplary object and its rotations.*

Question #14 of the PSVT-R test (Guay, 1977) is the same as question #17 in the original PSVT test (Guay, 1976). It is also included as question E in Figure 5.169 of a popular textbook (Bertoline & Wiebe, 2007). Since question #14 of the PSVT-R test is readily available, it has been chosen as an example to show some details of the errors. In the original PSVT-R test, the rotated views A and E both missed some features on the rear end of the object as placed (Figure 1). Figure 3 shows the corrected views A and E with the missing features visible as they should be.

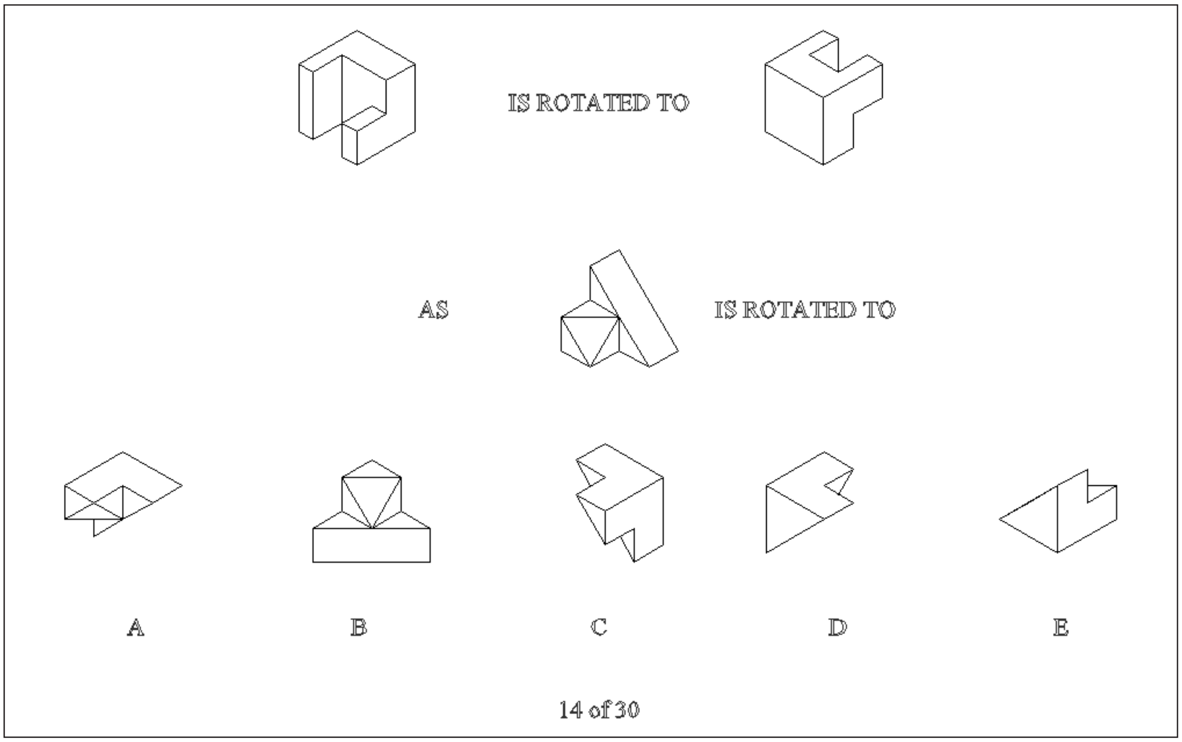

Figure 3: *Corrected views of the question 14 in the PSVT-R test*

The original PSVT-R test was created in the 1970s before the wide application of computer graphics and the isometric views were probably drawn by hand and instruments. This discussion of the errors in the original PSVT-R test is only intended to show the fact that isometric drawing is prone to errors. The drawing errors (Table 2) in the original PSVT-R test were found when the author recreated the objects into solid models during the research. In the past 30 years, the PSVT-R test has been administered to thousands of college students to assess their spatial visualization ability. It is not clear whether and how these errors in the test have affected the outcome of the students' performance.

IMPROVING 3D FEATURES FOR MORE REALISTIC PICTORIAL VIEWS

Some of the 3D features as listed in Table 1, such as perspective view and surface texture and material, may be further improved to produce more realistic pictorial views.

(a) Perspective view

The lines of view in isometric drawing are parallel to each other no matter where the objects are located. Since the line of sight in isometric drawing is aligned with the enveloping cube's body diagonal, the three viewable surfaces (top, front, and right-side) receive equal exposure, so that equally-sized surfaces will appear with the same size in the drawing. In isometric view, the features at various depths are also drawn with the same dimensions, and therefore, cause viewing distortion in depth. However, as a result of the parallel lines of projection and distortion in depth, all views in the original PSVT-R test appear uniform and easier to visualize by individual features (Figure 1).

While in a perspective view, parallel lines in the scene converge at a vanishing point on a horizon line. The perspective effect displays the actual view of a human eye and yields more realistic pictorial views. However, the surfaces of a 3D object receive unequal exposures when the object is placed off-center from the viewing axis, on the projection plane, and its features appear smaller in depth. As shown in the modified PSVT-R test (Figure 2), after rendering with a perspective effect, the right side surface of the object located to the far left on the projection plane receives more exposure than its left side surface, and vice versa when it is located to the far right. A specific feature on the object also appears larger in the front and smaller when it is rotated to the back. An example of realistic 3D views without a perspective effect is also shown in Figure 4. Compare with the realistic 3D views with perspective effect as used in the modified PSVT-R test (Figure 2).

(b) Surface texture and material

After extensive comparisons, a wood material was chosen in the modified PSVT-R test to provide a better view of the 3D objects. However, the wood grain was not embedded into the objects or uniquely associated with their surfaces. As a result, students are unable to make use of the wood grains as a reference feature in visualizing the rotations of the objects. It is debatable whether surface texture, which does not exist in isometric views in conventional visualization tests, should be incorporated into modified tests using realistic 3D views. The author believes that texture is a feature of real-life objects, and so should be included in spatial visualization tests to achieve maximum realism in pictorial views.

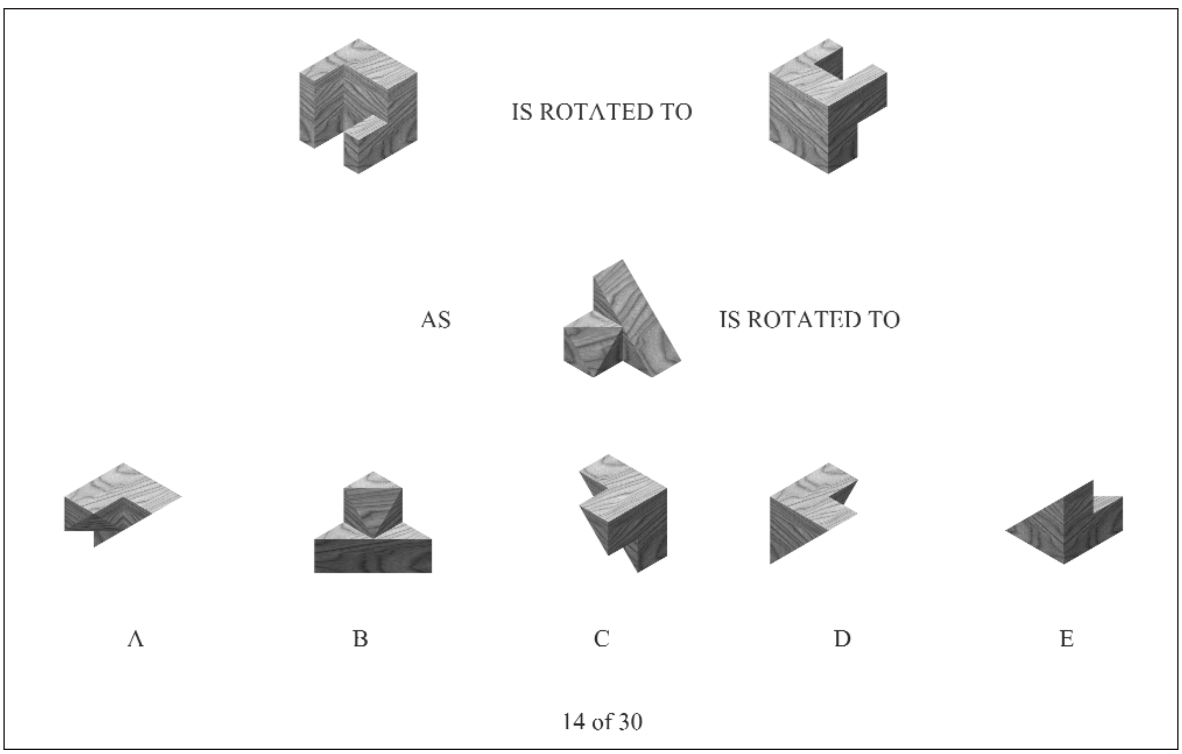

Figure 4: *Realistic 3D views without perspective effect*

RESULTS OF THE TWO SPATIAL VISUALIZATION TESTS WITH ISOMETRIC AND REALISTIC 3D VIEWS

TEST SUBJECTS

Essex County College is a two-year urban community college located in the downtown of Newark, the largest city in New Jersey. The student population of Essex County College has a high percentage of minorities including 51% of African Americans and 17% of Hispanics. The College offers an Associate in Science (A.S.) degree in general engineering; Associate in Applied Science (A.A.S.) degrees for several engineering technology majors, including Architectural Technology, Civil Construction Engineering Technology and Land Surveying, Electronic Engineering Technology, and Manufacturing and Mechanical Engineering Technology; and a certificate in CAD Technology. All of the engineering and technology majors are required to take two drafting courses: ENR 103 Engineering Graphics and ENR 105 Applied CAD except for the Electronic Engineering Technology program, which does not require ENR 105. ENR 103 is an entry level course for engineering and technology students, some of whom have to take a developmental mathematics course, MTH 092 Elementary Algebra, as prerequisite. ENR 103 is also the prerequisite for ENR 105 and both are 2 credit/3 contact hour courses.

From fall 1999 through spring 2002 many students took the original isometric PSVT-R test as the example shown in Figure 1 (Yue, 2000, 2002a, b; Yue & Chen, 2001) In spring 2005, the modified realistic 3D PSVT-R test (as the example shown in Figure 2) was given to several classes. The test subjects include those students who took ENR 103 and ENR 105 classes over the years (Table 3). Table 3 also includes several classes of high school students from Newark Technical Careers Center. These students were high school seniors who had already had CAD training in the high school and were taking ENR 105 at Essex County College under a scholarship to earn college credits.

Table 3: *Number of students tested*

Course	Isometric PSVT-R	3D PSVT-R
ENR 103 Engineering Graphics	56	36
ENR 105 Applied CAD	31	22
ENR 105 Applied CAD [a]	25	9
ENR 103 Engineering Graphics [b]	4	8

[a] *High school students*
[b] *Students in the comparison groups*

All students included in Table 3 took the tests in class at the beginning of each semester. The tests were supervised by instructors. Each test lasted approximately half an hour, and the test and answering sheets were collected by the instructors upon completion. The numbers of students actually taking the tests are much larger than those listed in Table 3 (Yue, 2000, 2002a, b; Yue & Chen, 2001). In order to make sure that the isometric and 3D PSVT-R tests are compared under similar conditions, the test subjects in Table 3 are selected for the study based on the following measures. First, in order to eliminate any possible retest effects, only the students who took the PSVT-R tests for the first time are selected. There are a few students who took the same test more than once in the course sequence of ENR 103 and ENR 105. In such a case, only first-time test scores are used in the study. In some classes, the same test was given at both the beginning and end of a semester in order to investigate course effects with a pretest and posttest. Only the pretest scores are used in the study. Second, the students are compared at the same educational level. The Essex County College students in the ENR 103 classes and the ENR 105 classes are compared separately. The high school students in the ENR 105 classes are also compared alone. Third, students in both day and evening classes took the tests. Many of the students in the evening classes not only were more mature and had working experience, but some of them also had prior college education. In addition, the students who took the realistic 3D test were all in day classes. Therefore, only day class students are included in the study.

In order to allow a random comparison of the scores among the same sample source, both the original isometric and the modified realistic 3D PSVT-R were given to students attending the same class in spring 2006. Fifteen students in an ENR 103 class took the two PSVT-R tests at the same time, with odd-number seated students taking one test and even-number seated students taking the other. There should be 7 and 8 students in the two tests. Unfortunately, three students taking the isometric test left a significant number of questions unanswered thus making their average scores unreliable. Therefore, we could only compare the test results between 4 students taking the isometric test and 8 students taking the realistic 3D test. The test scores of this class are also analyzed separately from other groups.

TEST RESULTS

The mean scores of the original isometric and modified realistic 3D PSVT-R tests for the four groups of students as listed in Table 3 are compared in Figure 5.

For the college students in the ENR 103 classes (Figure 5, ENR103), the 56 students earned an average score of 18.86 (63%) on the isometric PSVT-R test and the 36 students had an average score of 20.50 (68%) on the realistic 3D PSVT-R test, with an increase of 9%. However, the difference of the two mean scores is not found to be statistically significant [$t(90) = 1.154$, $p > .05$].

For the college students in the ENR 105 classes (Figure 5, ENR105), the 31 students scored on average 21.48 (72%) on the isometric PSVT-R test and the 22 students received an average scores of 21.77 (73%) on the realistic 3D PSVT-R test. But again, the mean score difference is found to be statistically insignificant [$t(51) = 0.188$, $p > .05$].

For the high school students in the ENR 105 classes (Figure 5, ENR105HS), the mean score of the 25 students was 17.92 (60%) on the isometric PSVT-R test and the average score of the 9 students was 20.56 (69%) on the realistic 3D PSVT-R test. There is a 15% improvement in students' scores on the realistic 3D test over students' scores on the isometric test. Even though the mean score difference is the largest in the four test groups, it is still not statistically significant [$t(32) = 1.410$, $p > .05$].

Finally, for the comparison groups of students who took the two tests at the same time and in the same class (Figure 5, ENR103COM), the average score of the 4 students who took the original isometric PSVT-R test was 20.00 (67%) while the average score of the 8 students who took the modified realistic 3D PSVT-R test was 21.25 (71%). The students' mean score on the realistic 3D test is higher than that of the students tested on the isometric test, with an increase of 6%; however, their difference is again not statistically significant [$t(10) = 0.309$, $p > .05$].

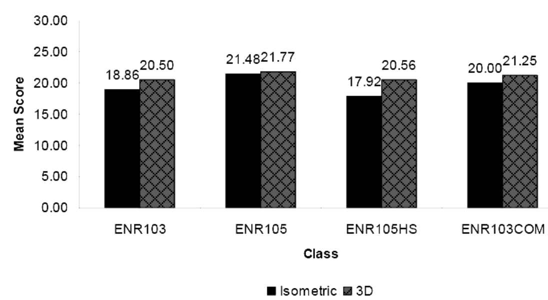

Figure 5: *Comparison of the mean scores of the isometric and realistic 3D PSVT-R tests*

DISCUSSION

As presented previously, this study has found improved performance by students on the spatial visualization test with realistic 3D views. For all four test groups, the mean scores on the realistic 3D test are higher than the mean scores on the conventionally used isometric test. The greatest improvement is by the group of high school students with an increase of 15% on the realistic 3D test. Computer graphics using 3D solid modeling and rendering can display far more realistic features than an isometric drawing, which probably contribute to students' better performance. The study results provide evidence that 3D solid model enhances students' performance on visualization tests, thus making it a better tool to be used in spatial visualization tests to help students visualize virtual objects and to allow educators to obtain accurate assessments of students' visualization abilities.

The marginal improvement, however, in students' performance on the realistic 3D visualization test may be explained by several factors. First, since the 3D views are displayed on a 2D computer screen, they still lack some features of a true realistic 3D view. Second, in spatial visualization by rotations, students tend to focus on specific geometric features (e.g. a concave or convex) on an object to visualize its orientation after each rotation. As a result, the additional realistic 3D features may not significantly help improve test performance in this type of visualization. These limitations indicate a need for further improvements of spatial visualization tests with more realistic 3D features. Rapid development and advancement of computer hardware and CAD software will allow us to further improve and perfect spatial visualization tests.

Similar studies, using improved realistic 3D views in spatial visualization tests administered to larger groups of students and different populations at four-year colleges, should be conducted to confirm the findings of the study. Studies using other formats to compare isometric and 3D visualizations are also necessary for engineering educators to gain different perspectives on and more insights into spatial visualization ability assessments.

CONCLUSION

In conventional spatial visualization tests in the past, the pictorial views of 3D objects were drawn by axonometric and mostly isometric views. Isometric views lack many 3D features, distort true pictorial views, and are prone to drawing errors. These drawbacks of isometric views may result in inaccurate assessment of students' spatial visualization abilities. Nowadays, the sophisticated features of advanced computer hardware and software allow us to develop powerful tools to create more realistic pictorial views of 3D objects. In this study, all groups of students showed better performance on the spatial visualization test with realistic 3D views than on the conventional isometric visualization test. In order to assess accurately students' spatial visualization abilities as exercised day-to-day in the workplace, it is necessary to replace isometric drawings with more realistic pictorial views in spatial visualization tests.

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