AC 2007-275: SPATIAL VISUALIZATION BY REALISTIC 3D VIEWS

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Spatial Visualization by Realistic 3D Views

Abstract

Spatial visualization skills are essential in many engineering and technology fields. These skills are especially important in hand sketching and computer-aided design (CAD) of engineering graphics, when it is necessary to visualize and represent three-dimensional (3D) objects and assemblies. Educators and researchers have developed various types of tests to assess students' abilities in spatial visualization tasks. Conventional visualization tests usually use axonometric drawings, mostly isometric projections, to represent 3D objects. However, isometric drawings are dimensionally distorted and lack many features present in a realistic view of 3D objects. They are also prone to drawing errors, which, when combined with the inherent distortions of isometric drawing, may lead to misjudgment of students' visualization abilities. In order to accurately assess students' visualization ability, realistic views are necessary in spatial visualization tests. To investigate the effects of 3D views, the author conducted a comparative study of a popular spatial visualization test given to the first-year graphics and CAD classes at a minority community college. The objects in the Purdue Spatial Visualization Test – Visualization by Rotations (PSVT-R) were recreated with 3D solid modeling CAD software to show more realistic views. The results from both the original test in isometric views and the same test with 3D solid model views are statistically analyzed. Also, a more detailed discussion is presented of the advantages of using solid modeling in spatial visualization tests, and the drawbacks of the conventional test using isometric drawings.

1. 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 [1] designed a test to investigate the reaction time of visualizing rotated 3D objects. Vandenberg and Kuse [2] later developed a test, based on Shepard and Metzler's model, known as the mental rotation test (MRT). Ekstrom [3] 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 [4] developed the Purdue Spatial Visualization Test (PSVT) which consists of 36 problems equally divided into three categories: developments, rotations, and isometric views. Guay [5] also expanded the problems of rotations into a 30-problem 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 [6, 7]. 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 [8-30]. A computerized version of the PSVT-R test, featuring additional references, such as Cartesian coordinate axes, has also been used [9, 22, 23]. Other variations of the test formats for spatial visualization have also been attempted [31, 32]. Recently, educators have begun to use CAD software to create solid models in spatial visualization tests for more realistic 3D views [14, 24, 31]. 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 multi-views or orthogonal projections of objects, students use CAD software to build a solid model first and automatically generate its multi-views 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 multi-views, 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.

2. The original PSVT-R spatial visualization test with isometric views

The PSVT-R test 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 problem, 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 problem #14 of the original PSVT-R test is shown in Figure 1 [5]. This problem is the same as problem #17 in the PSVT test [4], and also problem E in Figure 5.169 of a popular textbook [33].

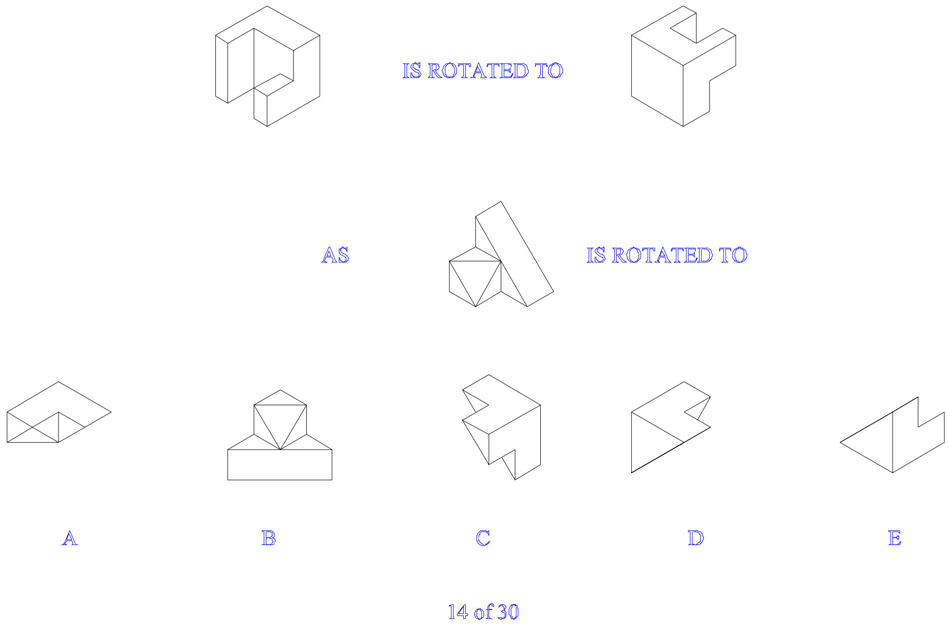

Figure 1 Original views of the problem #14 in the PSVT-R test [5]

3. 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 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.

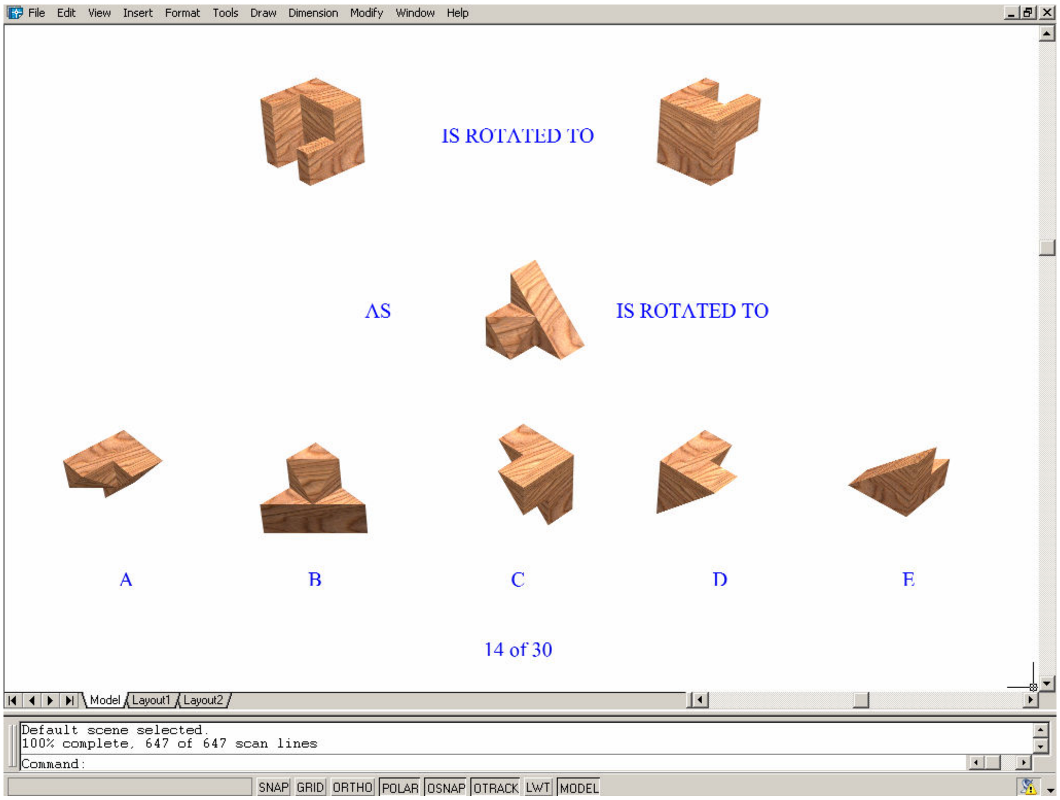

Figure 2 Realistic 3D views with perspective effect

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

4. Discussion of the original isometric and modified realistic 3D PSVT-R tests

4.1. 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 [5], 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 (Table 2) [34].

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 [5] is also the question #17 in the original PSVT test [4], and included in question E of Figure 5.169 of a popular textbook [33]. 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.

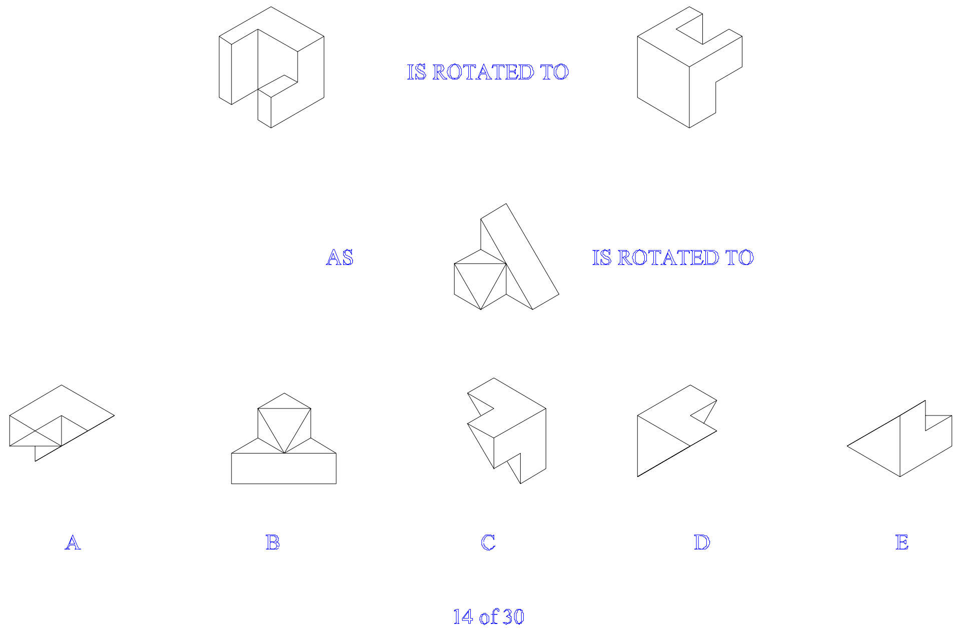

Figure 3 Corrected views of the problem 14 in the PSVT-R test

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 [8-30]. It is not clear whether and how these errors in the test have affected the outcome of the students' performance.

4.2. 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, frontal, 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).

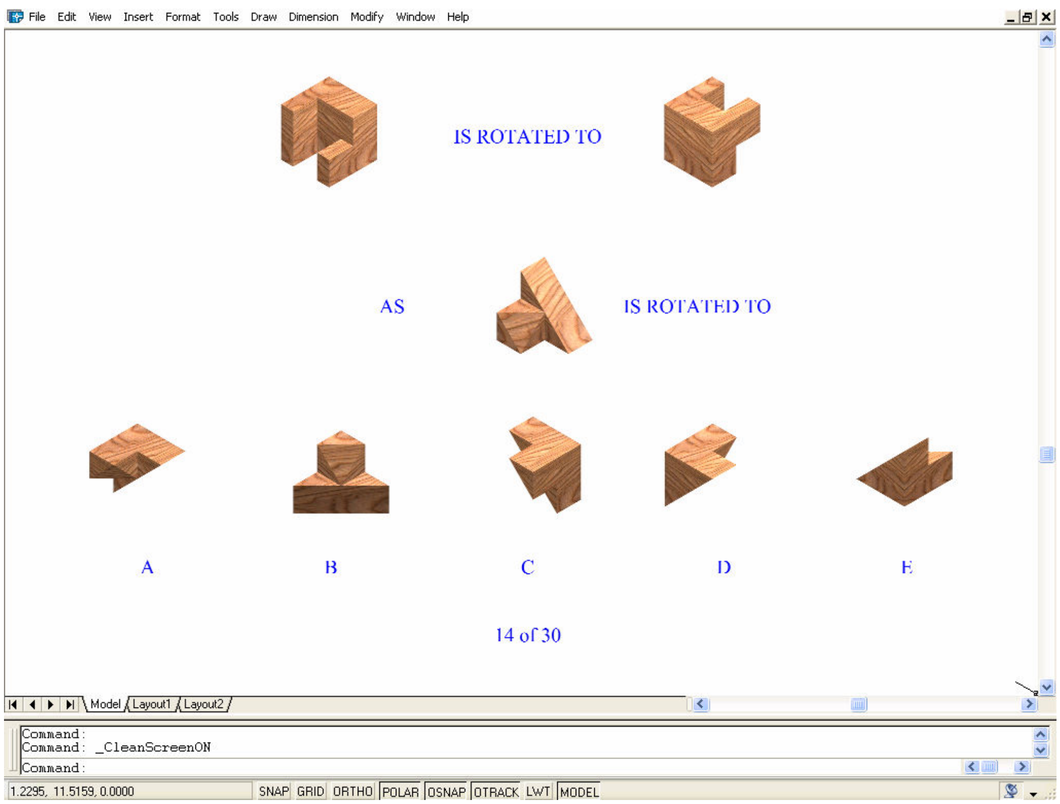

Figure 4 Realistic 3D views without perspective effect

(b) Surface texture and material

After extensive comparisons, a wood material was chosen in the modified PSTV-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.

5. Results of the two spatial visualization tests with isometric and realistic 3D views

5.1. 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 [5] (as the example shown in Figure 1) [18-21]. In spring 2005, the modified realistic 3D PSVT-R test (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 credit.

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 from Newark Technical Careers Center
[b] Students in the comparison groups from the same class

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 actual numbers of students taking the tests are much larger than those listed in Table 3 [18-21]. 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 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.

5.2. 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 all four test groups, the mean scores on the realistic 3D test are higher than the mean scores on the isometric test.

For the college students in the *ENR 103* classes (Figure 5, ENR103), the mean score for the 56 students in the isometric PSVT-R test and the 36 students in the realistic 3D PSVT-R test are 18.86 (63%) and 20.50 (68%) respectively. However, the mean score difference is not statistically significant [$t(90) = 1.154$, $p > .05$].

For the college students in the *ENR 105* classes (Figure 5, ENR105), the mean score for the 31 students in the isometric PSVT-R test and the 22 students in the realistic 3D PSVT-R test are 21.48 (72%) and 21.77 (73%) respectively. But again, the mean score difference is found to be not statistically significant [$t(51) = 0.188$, $p > .05$].

For the high school students in the *ENR 105* classes (Figure 5, ENR105HS), the mean score for the 25 students in the isometric PSVT-R test and the 9 students in the realistic 3D PSVT-R test are 17.92 (60%) and 20.56 (69%) respectively. There is a 15% improvement of the scores of the realistic 3D test over 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 scores for the 4 students took the original isometric PSVT-R test and the 8 students took the modified realistic 3D PSVT-R test were 20.00 (67%) and 21.25 (71%) respectively. The mean score in the realistic 3D test is higher than that in the isometric test, however, their difference is again not statistically significant [$t(10) = 0.309$, $p > .05$].

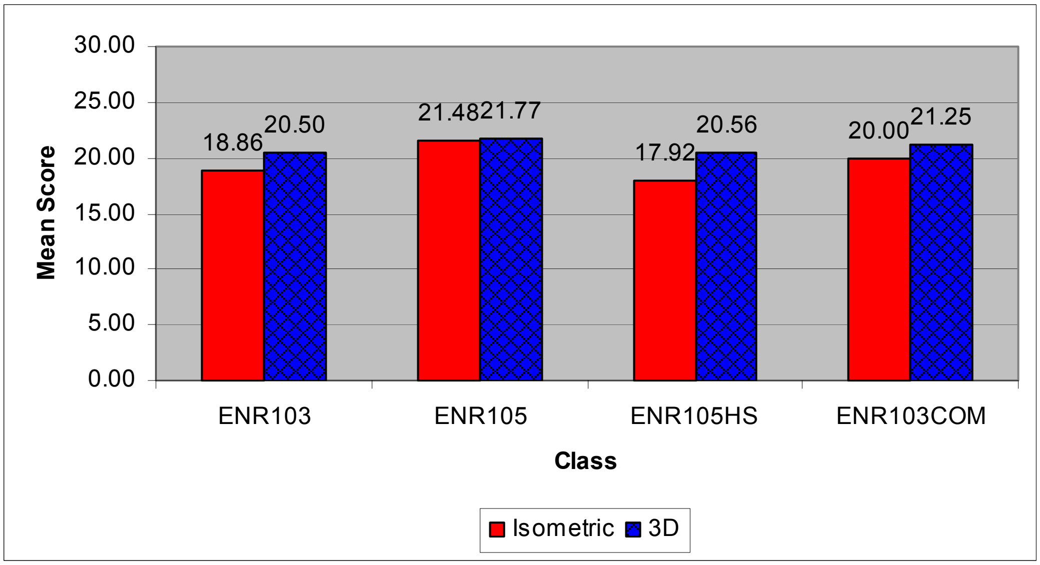

Figure 5 Comparison of the mean scores of the isometric and realistic 3D PSVT-R tests

6. 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. The drawbacks of isometric views may prohibit accurate assessment of students' spatial visualization abilities. Nowadays, the advancement of computer hardware and software can help to develop powerful tools to create more realistic pictorial views of 3D objects. In order to better assess students spatial visualization abilities as exercised day-to-day in employment, it becomes necessary to replace isometric drawings with more realistic pictorial views in spatial visualization tests.

In this study, the popular PSVT-R test in isometric drawings was recreated with 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 suggests enhanced performance on the spatial visualization test with realistic 3D views. The greatest improvement is by the group of high school students with an increase of 15% on the realistic 3D test (with a mean score of 20.56 or 69% in contrast with a mean score of 17.92 or 60% on the isometric test). However, none of the differences between the mean scores have statistical significance. Since the number of high school students who took the realistic 3D test was small (9 students), more studies are necessary to confirm the outcomes of using realistic 3D views in spatial visualization tests.

Although the study shows that students improved performance on the realistic 3D PSVT-R test, the improvement is not found to be significant, thus suggesting that the traditional isometric PSVT-R test and the realistic 3D PSVT-R test are not significantly different when assessing students' spatial visualization ability. However, more studies of using realistic 3D views in spatial visualization tests administered to different groups of students and on other campuses are needed to confirm this finding.

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