THE IMPACT OF 3-DIMENSIONAL SOLID MODELING ON IMPROVING THE VISUALIZATION SKILLS OF ENGINEERING DRAWING STUDENTS

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ABSTRACT

The purpose of this study was to determine if there is a difference in the improvement of visualization skills of form four Technical students in the state of Johor, Malaysia as measured by the Purdue Spatial Visualization of Rotation Test and Transformation of 3D to 2D Test through various interventions. Students were in one of two groups for this study. The experimental group consisted of students who were taking Engineering Drawing (ED) as one of their engineering elective subjects and who used 3D solid modeling software as an instructional tool; a control group was identified of students whose classes used a conventional learning method in ED. Instructional methods and materials designed by the primary author were used with a treatment group consisting of students enrolled in two sections of a pre-college engineering course. The primary research question asked if differences in gain scores on the visualization tests were obtained according to instructional method when pretest scores and gender were controlled for. Analysis of the mean difference was conducted to analyze the data for this research question. The dependent variable was the posttest score and the independent variables were pretest score and gender. A statistically significant difference was obtained between instructional methods, with the students using solid modeling software outperforming the students who used traditional instructional methods in terms of posttest scores.

Keywords: visualization skills, 3D solid modeling

1. INTRODUCTION

Visualization skills are an important aspect of human intelligence and are important for success in the today’s technological world. According to Bertoline (1998) and Sartain (1946; in Frey and Baird, 2000), visualization skills have become increasingly important for industrial development. The reason for this is that most products and technology that are developed today do not starts with geometry, mathematics or physics, but they start from visualizations and ideas in the minds of the people who will implement them (Ferguson, 1992). Compared to verbal ability, visualization skills have a stronger correlation with the technical domains, vocational occupations, and mathematics (Koch, 2006; Bertoline & Wiebe, 2003; Gillespie, 1995). Spatial visualization skills are especially important for technical and vocational areas involved with graphic communication during design activities, engineering drawings, technical drawings or even geometrical drawings. Hence, the ability to think and share ideas visually with others is vital to the design process in its early stages (Newcomer et al., 1999). Visualization skills have been shown to be important for success in engineering courses especially in engineering graphics (Leopold et al., 2001), in civil engineering (Alias et al., 2002), and in computer aided design courses (Sorby, 1999a). Spatial skills are especially important in engineering because engineers must not only be capable of generating new ideas but also able to communicate visually to others through drawings. Therefore, those students who enroll in engineering field should be exposed to topics in engineering drawing so that their visualization skills will continue to develop.

2. BACKGROUND

Solid modeling is an efficient tool in engineering design software technology. Through using this tool, dimensions on drawings can be changed easily to alter the geometry or shapes of objects during the design process. According to Koch (2006), Murray (2006) and Kurland (1994), solid modeling is an efficient design tool because it enables the user to easily transform dimensions on an engineering drawing or model. Modern-day parametric modeling software has several advantages as identified by Murray (2006). The advantages of this software are that it is easy to use, aids in visualization, is equipped with the ability to see the production and development process of a model, enables the user to correct any error in design immediately, allows for the determination of a material properties for a design, provides a mechanism to easily adapt engineering models to other graphic forms for marketing purposes or advertising, facilitates finite element analysis on the solid model, and may be linked directly to a manufacturing operation such as rapid prototyping or computer numerical control (CNC). Even though solid modeling software is advanced in terms of technology, computerized models are not always capable of replacing the basic function of physical objects due to restrictions in the hardware and software (Koch, 2006, Bertoline and Wiebe, 2003; Kurland, 1994).

AutoCAD is a popular geometric modeling software tool and is often used in engineering design and computer aided design courses at the university and polytechnics as well as in technical high schools (Mohd Safarin and Muhammad Sukri, 2007). This software can be used as a drawing and modeling tool to enable students to develop 2D geometrical drawings, wireframes, 3D surfaces and 3D solid models. However, in the context of technical high schools, typically only the 2D geometrical drawing applications of AutoCAD software are presented to students in Malaysia. Other applications, like 3D modeling, are usually excluded from the curriculum or lesson units at the secondary level.

The use of 3D solid modeling for design has several advantages over traditional methods such as accelerating the drawing process, simplify the drawing and editing processes, as well as make the design process one which can be accomplished at any time. The solid modeling tool enables a user to create multiview drawings representing the model automatically without having to redraw each view or each drawing (Batchelor and Wiebe, 1995). Utilization of 3D solid modeling also makes the process of preparing axonometric projection or perspective drawings easier. Even though 3D modeling software has made the drawing creation process more straightforward, usage of the tool requires users who are able to choose the suitable projection in order to present pictorial information accurately and clearly. Users must understand the fundamentals of projection theory in order to select the optimal projection angle, taking full advantage of the 3D modeling capabilities. In this way, perspective drawings will be based on the geometric features of the object and will no longer depend solely on conversions or interpretations.

The use of 3D solid modeling in the teaching and learning of ED would give students a visual experience where virtual objects look like the real objects. Therefore, students will be able to create a mental image easily and quickly by using the modeling software (Gorska, 2005). This means that the usage of solid modeling in the teaching process could help to improve the visualization skills of our students at all educational levels.

Braukmann and Pedras (1993) conducted a comparative study to determine the effectiveness of two different teaching methods regarding developing the visualization skills of college students. They found that the inclusion of the computer solid modeling method does not result in improvements in visualization skills or drawing ability. Devon et. al. (1994) tested the effect of solid modeling software on student's 3D visualization skills. The study involved pre- and post-testing in 13 sections of an introductory engineering graphics class to determine whether the use of solid modeling software (Silver Screen) would produce higher gain scores on a test designed to determine visualization skills when compared to the use of 2D CAD modeling and wireframe software. The Mental Rotation Test was used to measure the visualization skills of the participants in the study. The primary finding from the study was that the visualization skills of students from six sections of the fundamentals of engineering graphics class increased significantly. Therefore, the researchers concluded that the use of solid modeling will help students to improve their visualization skills.

Gillespie (1995) evaluated the effectiveness of solid modeling tutorials on the development of student's 3D visualization skills. This experimental study showed that there was a significant difference in visualization skills between groups of students who received 3D solid modeling instruction and the group who received traditional instruction. The study also investigated whether there is a significant difference between gain scores for students receiving treatment that consisted of solid modeling tutorials without limiting the exposure time period. Gillespie found that visualization skills can be improved by using solid modeling tutorials. Further, the study also found that students' visualization skills may be improved through other suitable methods of technical instruction and if solid modeling is one of the thinking techniques introduced to students, they will have increased competence in spatial visualization. Gillespie also found that all groups receiving treatment using the solid modeling tutorials increased their visualization skills regardless of the treatment period. Hence, Gillespie suggests that teachers or instructors must use the most efficient techniques to increase the visualization skills of their students.

A similar study was also conducted by Godfrey (1999) to compare and evaluate the effectiveness of 3D solid modeling versus orthographic and pictorial drawing with engineering and engineering technology students in terms of the development of spatial cognition. Godfrey's quasi-experimental studies involved two-groups of students, namely the control and treatment groups, which were tested before and after treatment. The control group in this study was exposed to traditional instructional methods in ED by which the students were asked to draw 2D mechanical drawings in order to develop spatial visualization skills. The experimental group used computer aided design software to create solid models and to develop 2D mechanical drawings from the models in order to develop the spatial visualization skills. The students from both groups were pre- and post-tested with the Purdue Spatial Visualization Test: Rotations (PSVT: R). The study found no significant difference between teaching methods which utilize 3D solid modeling and teaching methods which do not utilize 3D solid modeling in developing spatial visualization cognitive ability. Based on this work, Godfrey recommends that the emphasis in engineering graphics courses should be more on 3D modeling. In addition, the best approach would be to apply both 3D modeling and 2D drawing techniques in teaching engineering graphics concepts. The rationale for this is that the intellectual development from the concrete to the abstract is important in order to maximize student learning meaning that this approach will be more effective if the 3D instruction is delivered before the 2D instruction.

Sorby (1999a) conducted a study to determine the relationship between spatial abilities and computer aided design instruction at Michigan Technological University (MTU). This study has shown that instruction in the use of 3D solid modeling does not improve students' visualization skills comparable to instruction in traditional 2D techniqued. Students from various courses at MTU took several spatial tests before and after participation in the courses that employed different instructional methods and topics. The tests that were administered included the Purdue Spatial Visualization Test for Rotation (PSVT: R), the Mental Cutting Test (MCT) and the Mental Rotation Test (MRT). The courses examined in the study included a computer aided design course with an emphasis on 3D solid modeling, a sketching and freehand drawing-based engineering graphics course, and a third course that included an emphasis on engineering graphics and descriptive geometry. In the computer aided design course, significantly more than 50 percent of coursework was undertaken in a 3D solid modeling environment. Although the research showed that instruction in 3D modeling software does increase student spatial skills, the skill levels do not increase by as much as when 2-D sketching or drawing is the primary mode of instruction. In another study conducted by Sorby (2000), however, spatial skills as measured by the Mental Cutting Test were shown to be a significant factor in influencing a student's ability to interact with the computer in 3D solid modeling environment.

Mohammad Mehdi (1993) conducted studies on the relative effectiveness of computer graphics and animation in developing spatial visualization skills of engineering students enrolled in a fundamental university course in engineering design graphics. Computer graphics and animation were utilized as external stimuli that helped students develop a mental process essential for visualizing the objects in the engineering system. This quasi-experimental research study compared the achievement between two groups of students where one group received instruction via animation and the other one received instruction via static visuals. Several evaluation instruments such as quizzes, assignments and the Mental Rotation Test were used as pre- and posttest. Instructional topics followed by both groups were orthographic projection and sectioning. These topics were chosen because Mehdi believed that both topics require a high level of spatial visualization skills. The analyses of the results revealed that the group that received instruction via animation performed generally better on the Mental Rotation Test, quizzes, and assignments than the group that received instruction through static visuals. The group of students that received instruction via animation also earned a higher score on the orthographic projection and sectioning assignments compared to the group of students that received instruction via static visuals. Therefore, Mehdi concluded that the utilization of computer animation in presenting spatial objects helps students to improve their ability to mentally encode visual information especially involving mental rotation of object.

In Poland, studies were conducted between 1994 and 2004 with the students at the Cracow University (Gorska, 2005) in form of a series of pretests and posttests. The studies intended to determine the spatial ability level of engineering student at the Cracow University of Technology who enroll in courses in descriptive geometry. Several of the engineering students from the university attended computerized descriptive geometry courses while others attended descriptive geometry course taught through traditional means. The content for the descriptive geometry course which utilized the computer included construction of 2D objects and 3D modeling using AutoCAD. In 2D object construction, students learned how to create and control drawing entities, modify a drawing by or changing objects, and to rotate and mirror 2D objects. In the 3D modeling instruction, students learned how to create 3D objects using surface and solid modeling methods as well as learning about rendering and lighting the model. Gorska found that the students' achievement on the mental rotation test for the group of students who attended the conventional courses in descriptive geometry were higher than the group who attended courses which utilized AutoCAD software in instruction. The students' gain scores on the mental cutting test were nearly identical for the two groups.

Based on these previous studies the use of computers in courses such as descriptive geometry and engineering drawing does not guarantee an improvement in student visualization skills for mental rotation and mental cutting.

3. PROBLEM STATEMENT

Visualization skills have been extensively studied in science and technology disciplines, especially in the engineering field. There are several studies which have discovered new instructional methods to improve students' visualization skills such as the use of computer graphics software. However, the effectiveness of these methods has not been consistent across methods, techniques, and student backgrounds. Furthermore, there is an issue regarding how 3D solid modeling experiences affect the visualization skills of secondary school students who attend pre-college engineering drawing classes. The purpose of this study was to investigate the effectiveness of 3D solid modeling in developing visualization skills of technical stream students in a high school Engineering Drawing course in Malaysia.

4. RESEARCH QUESTIONS

Specifically, this study will answer the following questions,

a) What is a level of mental rotation and transformation skills among technical stream high school students before they are exposed to instruction in the subject of Engineering Drawing?

b) Is there an improvement in mental rotation and transformation skills among high school students who are exposed to 3D solid modeling instruction during an engineering drawing course?

c) Is there an improvement in mental rotation and transformation skills among high school students who are not exposed to 3D solid modeling instruction during an engineering drawing course?

d) Are there differences in mental rotation and transformation skills between male and female students before being exposed to engineering graphics instruction?

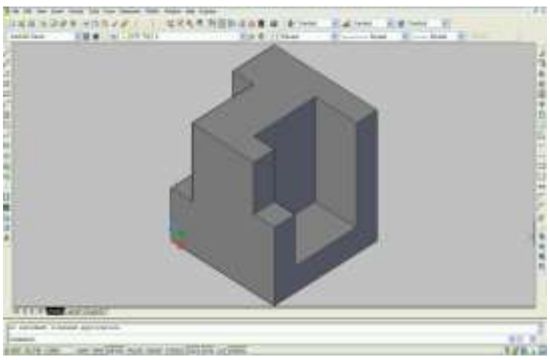
e) Are there any differences in gains in mental rotation and transformation skills between male and female students who are exposed to 3D solid modeling as an instructional tool in engineering drawing?

f) Are there any differences in gains in mental rotation and transformation skills between male and female students who are not exposed to 3D solid modeling as an instructional tool in engineering drawing?

5. RESEARCH METHOD

This quasi-experimental study involved 108 civil and mechanical engineering students from two technical high schools in the state of Johor, Malaysia. The sample was selected through a purposive sampling method. They were divided into two groups, the experimental and comparison groups. Each group consisted of 54 students. The students in the experimental group were exposed to the 3D solid models as instructional tools for the topic of orthographic projection as shown in Figure 1. Students in the comparison group were not exposed to the solid modeling application in the engineering drawing course.

Each group was tested with two types of visualization skills tests before and after receiving their respective treatment. The tests which were used to assess the students' visualization skills were the Purdue Spatial Visualization Test: Rotation (PSVT: R) and 3D to 2D Mental Transformation Test (3D2DMTT). The PSVT: R is used to test a person's mental rotation skills, while the 3D2DMTT is used to assess the student's mental transformation skills. A sample problem from the 3D2DMTT test is shown in Figure 2. This test was developed by the first author.



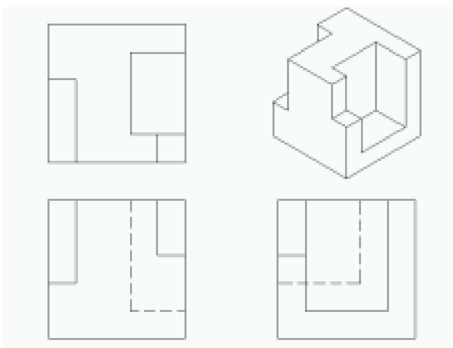


Figure 1: The application of 3D solid modeling in orthographic projection

2.

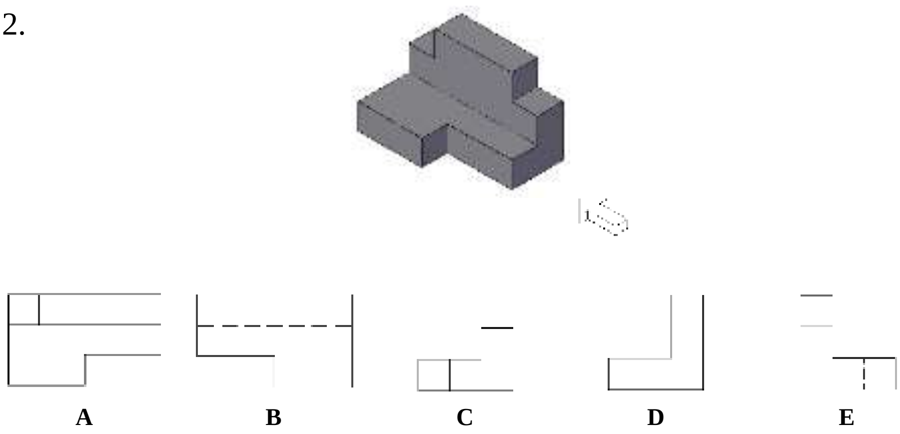


Figure 2: The sample problem of 3D2DMTT test

To analyze the results from this experiment, descriptive and inferential statistics were used to answer each research questions. The interpretation of the data was carried out based on an interpretation of spatial ability score level developed by Mohd Safarin and Muhammad Sukri (2007) as shown in Table 1. Basically, the level of spatial ability score has three levels which are 'above average', 'about average' and 'below average'. However, in the context of this preliminary study, the level of 'above average' is interpreted as 'High' visualization skills for scores between 61 and 100, 'Average' visualization skills for scores between 41 and 60, and the level of 'below average' is interpreted as 'Low' visualization skills for scores between 0 and 40.

Table 1: Visualization level interpretation based on Spatial Ability Score

Score (percentage)	**Visualization Skills Level**
61 – 100	High
41 – 60	Average
0 – 40	Low

6. RESEARCH FINDINGS

Table 2 includes pre-and posttest results obtained in the study. This data shows that that the civil and mechanical engineering studies high school students from both the experimental and comparison groups demonstrated high skill levels in mental rotation and transformation before enrolling in their engineering graphics courses. , The average pretest scores for students from the experimental (M=61.56, SD = 18.928) and comparison (M=619, SD= 21.222) groups on the PSVT:R was equivalent.The mean score of students from both groups is above average, therefore the level of students' mental rotation skills from both groups is interpreted as "high." The 3D2DMTT mean score for students from the experimental group (M=70.87, SD=17.539) was higher than that for the comparison group (M=65.69, SD=20.221), but both are still in the "high" skills category indicating that the students from both groups have high levels of skills in 3D to 2D mental transformation.

Table 2: Mean score of pre-/post-test in visualization and gain by group

Group	PSVT:R			3D2DMTT		
	Pretest	Posttest	Gain	Pretest	Posttest	Gain
Experimental	61.56	69.61	8.056 ($p < .001$)	70.87	78.28	7.415 ($p < .001$)
Comparison	61.39	62.20	0.815 ($p > .05$)	65.69	66.20	-.519 ($p > .05$)

The results from this study show that there was significant improvement in mental rotation and transformation of 3D to 2D skills among those high school students who were exposed to 3D solid modeling applications. The mean score for the experimental group on the PSVT:R posttest (M=69.61, SD=17.595) was higher than the mean pretest (M=61.56, SD=18.928). A paired-sample t-test found that there was a significant gain on the PSVT:R (M=8.056, SD= 10.594) among students from the experimental group. This improvement was significant at the level of t (53) = -5.587, p < .001. Similarly, the mean posttest on the 3D2DMTT (M=78.28, SD=15.365) for students from the experimental group was higher than the mean pretest (M=70.87, SD=17.539). The result of paired-sample test shows that there was a significant gain in 3D2DMTT score (M=7.415, SD= 7.417) and the gain was significant at the level of t (52) = -7.278, p < .001.

Meanwhile, this study also found no significant improvements in rotation and transformation of 3D to 2D skills among those students who were not exposed to 3D solid modeling applications. The mean posttest score for the comparison group on the PSVT:R (M=62.20, SD=23.022) was nearly identical with the mean pretest score (M=61.39, SD=21.222). The difference between the pretest and posttest scores was not statistically significant. The mean score on the 3D2DMTT posttest (M=66.20, SD=20.685) for the comparison group was slightly higher compared to the mean pretest score (M=65.69, SD=20.221) for the group. The increase was not statistically significant.

Using a t-test to compare the mean test score between male and female students, an interesting observation can be made. The results are summarized in Table 3 and show that male students have higher skills in mental rotation and transformation than their female counterparts before they are exposed to the 3D solid modeling application. The PSVT:R mean score for male students (M=70.64, SD = 16.694) is higher than that for female students (M=50.84, SD = 18.321). An independent sample t-test shows that the difference is significant at p < .001 (2 tails). Similarly, the 3D2DMTT mean score for male students (M=75.57, SD=14.648) is higher than that for female students (M=59.59, SD=20.091) and the difference is significant at p < .001 (2 tails). This means that male and female students have different levels of achievement in mental rotation and transformation before they are exposed to the 3D solid modeling application.

Table 3: Mean pretest scores of visualization skills by gender

Pretest	Mean Score		Mean score Difference
	Male	Female	
PSVT:R	70.64	50.84	19.798 ($p < .001$)
3D2DMTT	75.57	59.59	15.977 ($p < .001$)

n=108

Table 4 includes the mean gain scores (in percentage value) for the PSVT: R and 3D2DMTT tests for students in the experimental and comparison groups by gender. The results show that there were no significant differences in PSVT: R and 3D2DMTT mean gain scores between male and female students in the experimental group. This means that the utilization of 3D solid modeling in Engineering Drawing instruction helps to improve both male and female students' visualization skills. In addition, it appears that the intevention helps to bridge the gap of skills level between males and females somewhat. The results also show that there was significant difference in 3D2DMTT mean gain score between male and female students in comparison group. Female student's mental transformation skills have increased significantly even without exposed to 3D solid modeling application. On the other hand, the male students' mental transformation skills have decline significantly.

Table 4: Mean gain scores in PSVT: R and 3D2DMTT test by group and gender

Group	Gender	Gain means score			
		PSVT: R		3D2DMTT	
Experimental	Male	5.60	$p > .05$	6.84	$p > .05$
	Female	10.17		7.93	
Comparison	Male	2.18	$p > .05$	-1.39	$p < .01$
	Female	-1.33		3.52	

7. CONCLUSIONS

The findings from this study show that student performance in visualization skills can be improved through using 3D solid modeling applications in engineering drawing instruction at the high school level. The 3D solid modeling application helps students to develop their ability to visualize through manipulation of computer-based object representations that look like real objects. Through these computer representations, students not only obtain experience in learning about the engineering drawing subject, but they also reduce the occurrence of mistakes in visualization while learning abstract concepts such as orthographic projection. Further, students gain experience in space manipulation such as rotating and transforming virtual objects while using 3D solid modeling software.

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