EFFECTIVENESS OF 3D SOLID MODEL ON IMPROVING SPATIAL VISUALIZATION ABILITY FOR TECHNICAL DRAFTING STUDENTS

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ABSTRACT. *Spatial visualization ability is essential to the success in technical drafting students. However, as observed during classes and as reported from previous studies, students exhibit difficulty with the basic concepts of technical drawings and spatial visualization ability. To address this gap in the literature, this study aims to examine the effect of a 3D solid object as an instructional aid strategy to improve the spatial visualization ability among 30 Technology and Drafting students in a community college in Misamis Oriental, Philippines. This study employed an explanatory mixed method where a one-group pretest-posttest design was utilized to collect quantitative data. Personal interviews were subsequently conducted to gather data that will explain the numerical results. The research instruments were adopted from the Mental Rotations Test (MRT), Purdue Spatial Visualization Test: Visualization of Rotations, and Differential Aptitude Test: Space Relations (DAT:SR). Findings of this study revealed that the 3D solid object has significantly improved the students' visual spatialization ability as the sight, depths perception, and tactile senses are activated during their classes. Recommendations for curricular planning and future studies are discussed in this paper.*

Key Words: 3D Solid Model, explanatory mixed-method, Philippine Community College, Spatial Visualization Ability, technical drafting students

1. INTRODUCTION

Background and Rationale of the Study

The process of interpreting Technical Drawings requires strong spatial visualization ability which has been shown to be important in many areas including the engineering and technology field [1]. Spatial visualization ability (SVA) has been shown to be important to the success of engineering graphics [2]. Engineering graphics are taught in technical drafting courses. Students who are enrolled in a technology drafting course should acquire an understanding of the basic concepts of technical drawings and SVA to guide them in understanding the complexity of learning engineering graphics. The improvement of students' SVA is very important in technical education, which is typically found in the first-year Technology Education and Industrial Technology curriculum [3].

McGee as cited in the book of Lieu and Sorby (2009, pp. 3-5) [4] defined SVA as "the ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimulus objects." Howard Gardner as stated in the book of Lieu and Sorby [4] explained that spatial intelligence is one of the basic human intelligence, which is "the ability to perceive the visual-spatial world accurately and to perform transformations on those perceptions." In other words, spatial visualization is the ability to manipulate an object into an imaginary 3-dimensional (3D) space and create a representation of an object from a new point of view.

The researcher has observed, based on personal experiences, that several college students taking up technical drawing struggled on their SVA in visualizing multiview drawings from their 3D counterparts. Most of these problems arise in the construction of orthographic or multiview and isometric projection drawings where complex shapes, rotational views, and figures are involved. These issues exist because technical drawing should have the fundamentals of SVA where the subject involves mental rotation, mental cutting, mental folding, transforming 3D to two-dimensional (2D) figures, multiview, and pictorial projections [5]. According to Chedi [6], the most difficult skill of a student taking a mechanical engineering course is the visualization of the view of an object and generating a 3D mental image of that object. Poorly developed spatial skills may hinder the success of learners in fields of engineering and technology [4]. Visualization problems is one of the major challenges in teaching technical drawing which opens more plausible techniques or methods to address this problem [6].

Effective tools and methods of enhancing and measuring the improvement of SVA have been a topic of concern in the past years. A study conducted by Alias, Black, and Gray [7] which was to test the effects of visual abilities on civil engineering college students with the aid of manipulative and sketching activities concluded that spatial activities could improve the SVA of students in all ages. Also, the study of LeBow, Bernhardt-Barry, and Datta [8] on Improving SVA using 3D printed blocks on 6th graders was effective in improving scores on the modified Purdue Visualization of Rotation Test (mROT) regardless of the student's gender, socio-economic status, or language. With the increasing usage and popularity of solid modeling nowadays, the use of 3D solid objects as an instructional and learning aid is a very real possibility. According to Jovanovic and Jones [3], using 3D solid models as visualization aids has a great potential for the improvement of SVA in Industrial and Technology Education courses. This presents an opportunity to develop more effective tools for the stimulation of visual skills on those students enrolled in technology education programs like technical drafting.

This study aims to examine the effect of a 3D solid object as an instructional aid strategy to improve the SVA among Technology and Drafting college students. Specifically, this study seeks to answer the following research questions:

1. Is there a significant difference in the mean scores between pretest and posttest in terms of:
    a. Mental Rotations Test (MRT)
    b. Purdue Spatial Visualization Test: Visualization of Rotations, and

c. Differential Aptitude Test: Space Relations (DAT:SR) of spatial visualization ability for Technical students?

2. How has the 3D solid object helped the technical drafting students in mastering orthographic drawing competencies?

2. METHODOLOGY

Research Design

The goal of this study is to examine the effect of a 3D solid object as an instructional aid strategy to improve the SVA among Technology and Drafting college students. This study utilized the explanatory mixed-method research design involving a one-group pretest-posttest design. Personal interviews were subsequently conducted to gather data that will explain the numerical results. An explanatory sequential design, according to Creswell and Plano Clark [9], consists of first collecting and analyzing quantitative data and then collecting and analyzing qualitative data to help explain or elaborate on the quantitative results. The rationale for this approach is that the quantitative data and subsequent results provide a general picture and understanding of the research problem. The qualitative data collection is needed to refine, explain or extend the statistical results by exploring the participants' views in more depth [9].

The Respondents of the Study

The participants of the study comprised of 1st year and 2nd-year students taking Bachelor of Technology and Livelihood Education (BTLED) at a community college in Misamis Oriental, Philippines of the first semester during the school year 2020-2021. There were 30 student-participants who were selected through purposive sampling technique They were chosen based on the following inclusion criteria: (a) they must be a registered student in a Technology Teacher Education course, and (b) they must have enrolled in a Technical Drafting course. The demographic profile of the respondents is presented in Table 1.

Table 1. Demographic profile of the participants of the study

Characteristics		Frequency	Percentage
Age	15 to 20 years old	14	45
	21 to 25 years old	8	26
	26 to 30 years old	5	16
	31 to 35 years old	4	13
Sex	Female	23	74
	Male	8	26

Research Instrument

The research instruments used to gather data for this study were adopted from a series of a standardized test of Mental Rotations Test (MRT) by Vandenberg and Kuse (1978) [10], Purdue Spatial Visualization Test: Visualization of Rotations by Guay, R. (1977) [11], and Differential Aptitude Test: Space Relations (DAT: SR) by (Bennet, Seashore, & Wesman, 1973) [12]. These instruments were used as the assessment standard. The students' mental rotation abilities were assessed before and after the 3D solid object was implemented as an instructional intervention. Moreover, an interview protocol developed by the researcher and validated by two qualitative researchers, was used during the personal interviews with the participants.

Development of the 3D Solid Object

The 3D solid object that used in this study is a simple cube-like solid (Figure 1). The 3D solid figure was conceptualized by the researcher with different geometrical forms on each side of the object to give an appearance of uniqueness in each view. The design of the 3D model was first designed through Google SketchUp solid modeling software and then drawn, assembled, and formed with the use of thick chipboard. The 3D solid object was then coated with colors representing the different views.

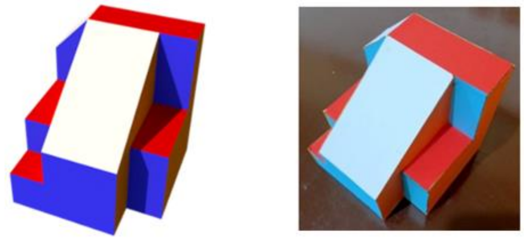

Figure 1. Computer-rendered model (left) and the physical-made model (right) of the 3D solid object that was used in this study

Scoring Guidelines

The pretest and posttest used in this study consisted of items from spatial visualization standardized tests (Mental Rotations Test, Purdue Spatial Visualization Test: Visualization of Rotations, and Differential Aptitude Test: Space Relation). In the Mental Rotations Test (MRT), the participants are required to choose which two of the four represented choices are the actual rotated replicas of the geometrical target figure. Each item was scored as one point if the participant correctly chose the two correct views. In Purdue Spatial Visualization Test: Visualization of Rotations, the participants were asked to choose which of the five options is the correct view representing the next rotation in the pattern. Each item will be scored as one point if the participant correctly chose the one correct view. For the Differential Aptitude Test, the participants were required to "mentally fold" the 2D pattern and choose the correct 3D object, which would result in the original 2D pattern, from four alternatives. Each item was scored as one point if the participant correctly chose all the correct patterns.

Data Collection

The pre- and post-test scores were collected through Google Forms by requiring the students to answer the three spatial visualization standardized tests before and after the implementation of the 3D solid object. The pre-test was conducted on 15 January 2021. Afterwards, the 3D solid object was utilized as a teaching intervention during the three-week online and on-site classroom instruction.

The solid object was implemented through online and on-site classroom instructions on orthographic and isometric lessons following Covid-19 precautionary measures after the pre-test was conducted. Students were allowed to use, hold and rotate the solid object as they answer orthographic exercises.

On 5 March 2021, the post-test was administered. The items in the pre-test and post-test were not the same but similar items. After the analysis of the pre- and post-test scores, personal interviews with the participants of the study were conducted. The personal interviews were carried on between 8 – 27 March 2021 following strictly the health protocols set by the government during the Covid19 pandemic. The English language and Local dialect were used in the interview to ensure clear understanding. The conversation was audio-recorded with the approval of the participants to ensure uninterrupted flow of the interviews.

Data Analysis

In the analysis of the data, the researcher used descriptive statistical techniques such as frequency count and percentage to profile the respondents; the mean and standard deviation to describe the level of students' spatial visualization ability; and a one-sample t-test to determine the significant difference between the pre-test and the post-test scores of the participants. For the qualitative data analysis, the researcher used thematic analysis. In thematic analysis, the researcher closely examined the data to identify the participants' thoughts and experiences through answering interview questions after performing the hands-on solid object rotational visualization.

Ethical Considerations

Prior to the collection of data, the researcher asked permission from the college administration. It was only upon the receipt of signed approval from the college administration did the researcher proceeded with the conduct of the study as well as in data collection. Request letters to involve the participants in the study were also given to the participants prior to the collection of data. They were informed that their participation is voluntary and that they are free to withdraw at any time. To protect the participant's identities, their names were replaced with codes. S1 refers to Student 1, S2 for Student 2, and so on. Since the study was conducted during the Covid19 pandemic, strict health protocols and precautionary measures were followed throughout the duration of the study.

3. RESULTS AND DISCUSSION

The results presented in this section sought to answer the first research question of this study which was intended to determine if there is a significant difference in the mean scores between pretest and posttest in terms of (a) Mental Rotations Test (MRT), (b) Purdue Spatial Visualization Test: Visualization of Rotations; and (c) Differential Aptitude Test: Space Relations (DAT:SR) of spatial visualization ability for Technical students.

Mental Rotation Test

One sample T-test was performed to test the significant difference in the mean scores between pre-test and post-test for the Mental Rotation Test of the participants of this study. The results from the pre-test *($M = 1.61, SD = 1.61$)* and post-test *($M = 1.97, SD = 1.30$)* revealed that the 3D solid object, used as a teaching strategy to teach 2D and 3D concepts in technical drafting class has significantly improved the students' spatial visualization ability *$t(30) = 8.41, p<.001$)* as indicated in Table 2.

Purdue Visualization Test

One sample T-test was performed to test the significant difference in the mean scores between pre-test and post-test for the Purdue Visualization Test of the participants of this study. The results from the pre-test (*$M = 1.29, SD = 1.243$*) and post-test (*$M = 1.06, SD = 1.389$*) as indicated in Table 3 revealed that the 3D solid object, used as a teaching strategy to teach 2D and 3D concepts in technical drafting class has significantly improved the students' spatial visualization ability *$t(30) = 4.267, p <.001$).*

Table 2. Mean, SD and significant difference between pre-test and post-test for Mental Rotation Test

	Mean	SD	t-value	df	p-value	Remarks
Pre-test	1.61	1.61	5.59	30	p<0.001	Supported
Post-test	1.97	1.30	8.41	30	p<0.001	Supported

Table 3. Mean, SD, and significant difference between pre-test and post-test for Purdue Spatial Visualization Test

	Mean	SD	t-value	df	p-value	Remarks
Pre-test	1.29	1.243	5.778	30	p<0.001	Supported
Post-test	1.06	1.389	4.267	30	p<0.001	Supported

Differential Aptitude Test: Space Relations

One sample T-test was performed to test the significant difference in the mean scores between pre-test and post-test for the Differential Aptitude Test: Space Relations Test of the participants of this study. The results from the pre-test *($M = 1.55, SD = 1.387$)* and post-test *($M = 2.10, SD = 1.599$)* revealed that the 3D solid object, used as a teaching strategy to teach 2D and 3D concepts in technical drafting class has significantly improved the students' spatial visualization ability *$t(30) = 7.301, p <.001$)* as indicated in Table 4.

Table 4. Mean, SD and significant difference between pre-test and post-test for Differential Aptitude Test: Space Relations

	Mean	SD	t-value	df	p-value	Remarks
Pre-test	1.55	1.387	6.218	30	p<0.001	Supported
Post-test	2.10	1.599	7.301	30	p<0.001	Supported

These results of the data analysis agreed with the findings in the study of Jovanovic & Jones [3] and of LeBow, Bernhardt-Barry, & Datta [8] emphasizing that using 3D solid objects as physical aids has huge potential to improve the spatial visualization abilities of students. In addition, it should be noted that 71% of the research participants (F=22) are aged 25 years old and below (see Table 1). According to the study of Salthouse et al. [13], older adults perform worse in SVA compared to younger adults. This perhaps explains why the results of the study is highly significant. Another factor that may have contributed to the significant influence of 3D objects on the improvement of the SVA is the sex of the respondents. Table 1 shows that 74% of the respondents are female (F=23). These findings disagree with the results of the study of LeBow, Bernhardt-Barry, & Datta [8] which showed that males perform better in SVA using a 3D object. Furthermore, in the study of Sorby et al. [14] on Developing 3D SV Skills for Non-engineering Students, he concluded that women tend to use manipulatives and can learn more than males whenever it is available.

Thematic Analysis

The findings presented in this section sought to answer the second research question of this study which states: How has the 3D solid object helped the technical drafting students in mastering orthographic drawing competencies? Personal interviews were done to collect the data in order to provide an in-depth understanding of challenges that the students encountered during their technical drafting learning activities. A directed content analysis approach was employed in the thematic analysis of the data from thirty personal interviews conducted.

Following the direct content analysis approach, there were three main themes that emerged in the data analysis. These three main themes are labeled (a) visual, (b) depths perception, and (c) tactile. Excerpts of the participants' narratives during the interview with their corresponding nodes, categories, and themes are presented in Table 5.

Visual

The visual theme has only one category, which is color and is further supported by 26 statements. Students, during the personal interviews, shared that using the solid 3D object visually helped them in understanding the conversion of 2D drawings to 3D.

Each side of the 3D solid object is indicated with the corresponding color, hence, according to S11, "*it is easy to visualize any side because the color pattern can be followed when rotating the object"* of which S15 agrees by saying that the different colors *"help identify when rotating the object."* These narratives from the participants imply that learners can determine visual orientations easily through colors. According to the study of Katsioloudis *et al.* [15], the application of color in 3D object benefit more to learners with low SVA than with high SVA learners. This may also explain that since the participants of this study have only taken one basic drafting subject which improves their SVA less than those learners taken up engineering degree, integration of colors in the 3D solid object that they use on this study may have more effect on their SVA.

Table 5. Themes that emerged from the personal interview data

Narratives	Categories	Themes
1. The appealing colors and proportional colors help in the depiction of the drawing (S18) 2. I can memorize and emphasizes its color (S20) 3. It is clear to see the colors and I could recognize the area/space with color (S24)	Color	Visual
1. I can easily see what the position is (S3) 2. I can easily determine the position of the object (S30)	Positional identification	Depth Perception
1. I can identify that the rear view is in the back of the solid object (S25) 2. The 3D object reflects the angle of the different views which is	Angular identification	
1. When you hold the solid object and see it in the top portion and then you can see the top view (S21) 2. I can perform the visualization if I can hold the 3D object in actual (S4)	Easy to hold	Tactile
1. It is very easy to visualize the solid object when I turn it to different directions (S8) 2. It is easy to learn because I know how to rotate the object (S5)	Easy to rotate	

Depth Perception

The depth perception theme is composed of three categories namely, positional and angular identification, and supported with 28 statements. During the interview, S4 mentioned that they can "*easily determine what is the position of a 2D against the 3D"* using the 3D solid object. Because of the different colors used in the 3D solid object, S28 and S30 shared that it *is "easy to determine the exact position."* In addition, S25 and S26 narrated that "*the solid object has different angles and forms which can be rotated"* and that "*each side can be determined by its angle and the corresponding color,"* according to S28. According to Boyd [16], depth perception is the ability to perceive things in a 3D perspective and to judge the distance of an object. In this study, the 3D solid object was used as a teaching aid in the learner's perception of depth which may indicate that physical 3D objects may help stimulate the participant's perception of depth including its length, width, positions, and different angle positions when they use the solid object. The theory of Multiple Intelligences by Howard Gardner [17], explained that spatial intelligence is basically an ability to recognize the visual-spatial world accurately and to perform transformations on individual perception.

Tactile

The tactile theme is composed of only two categories, namely: easy to hold and easy to rotate. This theme is supported by 15 statements. S6 shared that the size of the 3D object makes it "easy to hold" and thus S14 mentioned that students *"can rotate the object"* in order to view the different sides. S3 further mentioned that when students *"can easily visualize the views"* because they can "*perform it and do the learning on actual manipulation."* S9 also mentioned that the 3D solid is *"easy to rotate,"* hence it is *"very easy for the students to visualize the solid object when they can turn it to different directions."* Hands-on learning is very important for those students who learn better by doing. Tactile learners prefer touching, moving, building and can focus easily if they can manipulate objects rather than writing and listening [18]. In the study of LeBow [8] concluded that physical aids like the 3D solid objects can improve SVA in students. This may indicate that the participants of this study can visualize the different views of the 3D solid object easily by holding, manipulating, and rotating it at different angles. According to Gardner [17] in his theory of multiple intelligences, Bodily-kinesthetic Learners are those learners that possess the ability to move and handle physical objects skillfully.

4. CONCLUSION

This study utilized a 3D solid object as an aid in improving the SVA of college students taking up drafting subjects in a community college in Misamis Oriental, Philippines. Pre- and Post-Test scores in MRT, PSVT: R, DAT:SR was compared to determine the effects of SVA on students. The result showed that the pre- and post-test of MRT, PSVT: R, DAT: SR has significant differences which revealed that the 3D solid object, used as a teaching strategy to teach 2D and 3D concepts in technical drafting class, has significantly improved the students' SVA. Although the 3D solid object that was used in this study was not 3D printed, the results may still suggest that the curriculum for technical education in the Philippines today should integrate more physical aids and hands-on activities in their instructions specifically in technical drafting, since rapid prototyping using the 3D printer are now accessible in some parts of the country.

For future researchers, it is suggested to use this study and integrate different types of physical solid modeling and integrate it in a school setting. It is also suggested to use more diverse research models and instruments to further explore and understand the potential of improving SVA on teaching and learning experiences and to cater to a wide array of participants with visual-spatial intelligence.

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