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DOES Sketchup Make Improve Students' Visual-Spatial Skills?

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ABSTRACT This study was conducted with two objectives: (a) to develop 3D geometry teaching strategies through SketchUp Make (SPPD-SUM), and (b) to study the effect of SPPD-SUM on visual-spatial skills (VSS). It was conducted in two stages. Stage I involved designing SPPD-SUM, whereas Stage II involved studying of the effect of SPPD-SUM on VSS. The activities in Stage I were based on a five-phase cycle in the ADDIE Model. The analysis phase examined the basic information related to VSS. The design phase involved setting VSS into learning activities. The development phase involved the construction of learning activities that are in line with every VSS component. The implementation phase involved two series of pilot studies and the implementation of SPPD-SUM among 12 students for three weeks. The data obtained from the evaluation phase by seven mathematics experts found that SPPD-SUM might function well pedagogically. Stage II began with descriptive quantitative data and inferential statistics using a one-group quasi time series experimental approach. The study was conducted for six weeks among 34 form-five students. The inferential analysis via the mean score of VSS suggests that SPPD-SUM helps improve students' VSS with a significant difference (at $p = 0.05$ level) before and after learning activities. This quantitative analysis shows that there is a significant change in students' cognitive processes, particularly in their ability to rotate, view, transform and mentally cut 3D objects, and to identify, analyse, connect, and make series reasoning and geometric features. Therefore, it can be concluded that SPPD-SUM can be used in mathematics classrooms to improve students' visual-spatial skills.

INDEX TERMS Geometry learning, visual spatial skills.

I. INTRODUCTION

A. DIFFICULTIES IN VISUAL-SPATIAL SKILLS

Reference [1] presented the meaning of VSS as intelligence encompassing spatial, pattern forming, drawing, creating, coloring, developing mental illustrations, and observing the visual world. Reference [2] defined VSS as the ability to manipulate objects in the 3D imagination and to construct an image of an object from a new perspective. VSS is an ability that exists naturally but can be honed, mastered and enhanced [3]. Studies by [4] are also of opinion that individuals with less ability in VSS can be trained in the learning process to enhance their VSS. Reference [5] found that students often experience difficulties in geometric drawing due to weaknesses in their VSS. Reference [6] and [7] showed that developing teaching materials in

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technology can help students improve their VSS. VSS was also found to have a positive correlation with students' achievement in mathematics. This is because the ability to create a mental image of an object and then to manipulate it mentally is a practical and meaningful application in the field of mathematics. Meanwhile, training activities such as designing, research planning and workflow are highly emphasized in the field of employment. In solving such problems, the model must be mentally created first regardless of the actual form of the picture. As such, problem solving requires some VSS based on learning activities. The ability to describe objects and situations in one's mind as well as to manipulate the images formed is an important cognitive skill to most career fields especially graphics and geometric drawing. In addition, VSS has also been identified as the basis for high-level thought processes namely reasoning and creativity. Yet, the visual skills of Malaysian students are still at a low level. Based on a spatial visualisation test conducted at an early stage, reference [5] found that the number of students with lower visualisation ability is smaller (53 students) than those with higher visualisation ability (19 students).

Visualisation is important when one is confronted with an object for the first time. In this context, the natural reaction is to try to rotate and understand its shape and physical properties by taking into account several perspectives. All humans have the ability to process visual information, but they differ in terms of speed and velocity. Several past studies claimed that VSS is not effective if taught through regular teaching methods. This VSS is expected to be learned through life experiences. Students who are exposed to environmentally appropriate learning contexts will potentially have a stronger VSS. The evaluation of VSS usually involves a specific testing approach to determine the effectiveness of an intervention or treatment. A spatial ability test is usually used to identify the components of VSS that are difficult for students to master by determining the level of students' achievement in the four components of VSS, namely the ability to rotate, view, transform, and cut mentally. Some of the tests that are often used in measuring the components of VSS include the Spatial Ability Test, such as PSVT: R, PSVT: V and MCT, which was used by the researchers in the current study.

Learning geometry especially 3D Geometry requires VSS especially the representation of 3D objects to a 2D view. Cross-sectional visuals of objects are difficult to master by students who do not have the strong basic knowledge of the object. Additionally, there are several concepts in geometry that require students to make descriptions of objects and to identify features by distinguishing them from existing experiences. This concept of geometry also requires a visual interpretation of geometric problems presented in 2D in question papers. If students fail to extract 3D Geometry information drawn in an isometric view on paper, they may have difficulties in interpreting questions involving solid Geometry.

In addition, in a study of 26 trainee teachers at the Institute of Teacher Education [8], it was revealed that the trainee teachers face difficulties in determining the center of rotation that is not at the point of origin in the title of transformation. The failure to master drawing skills and the difficulties in VSS force them to allocate a long time in solving a given problem. Similarly, a study by [9] among form-four students found that 28 out of 32 students (87.5%) score below 50% in a test involving the circle title. Five of the 32 students obtain a zero score in the test. It was also found that the majority of the students are weak in VSS. In addition, the students are unable to interpret and extract important information from the given data.

In addition, many students fail to interpret the appropriate information from the data given. In this situation, they are unable to devise a solution and subsequently fail to draw conclusions. Students who have problems in parsing, interpreting and understanding what they see or hear will fail to process a given problem. In relation to that, VSS is very important in the learning of geometry. Learning in a traditional approach is more likely to force students to memorize. In this approach, there is less emphasis on how to think and create a (visual) picture in making decisions or solutions. This learning style often brings dissatisfaction to students.

VSS is one of the important skills that are closely related to real human life, especially in today's world of technology. Centered on an industrial development, VSS has become an indispensable skill. A higher level of VSS predicts students' achievements in science, technology, engineering, and mathematics. Therefore, improving VSS is important both theoretically and practically. This is because almost all technological products created at this point are not only due to knowledge of geometry, mathematics, physics or other branches of knowledge, but also due to the illustration of an image in the mind of one who then visualizes it. VSS has a correlation with technical, mathematical, vocational and occupational elements compared to verbal communication skills. In addition, computer-assisted learning of geometry is highly encouraged in heading towards 21st century learning. According to [10] and [11], computer-assisted learning is claimed to be a catalyst to learning in the classroom. Therefore, software-assisted learning, such as AUTOCAD and Geometer's Sketchpad (GSP), has been introduced among mathematics teachers. However, teachers use less of this software in schools. This is due to the difficulty of mastering the software and the limited use in the classroom [12]. This situation causes teachers to teach geometry by relying on textbooks and relatively limited study aids [13], [14]. Students are also forced to use their limited shadow skills to learn 3D geometry topics. Eventually, they may end up memorizing all the concepts without really understanding them. In the mathematics classroom in secondary schools in Malaysia, the use of technology is clearly stated. One of the technologies is SketchUp Make.

To overcome this problem, we designed and developed a new learning approach by applying visual-spatial skills (VSS) into learning activities with the help of SketchUp Make dynamic 3D modeling software known as SPPD-SUM. SketchUp Make is free software. It is user-friendly and easy to learn. It can be downloaded from the Internet for free and, most importantly, it can be used without an Internet connection. Therefore, students can download and use it on home computers besides using it in school labs. SPPD-SUM gives students the opportunity to learn independently and discuss with friends based on step-by-step instructions and guidance. The teacher only acts as a facilitator who ensures that the students use the correct terminology for the features of the Geometry involved. The teacher also addresses the confusion that may arise among the students throughout the activity. This environment provides opportunities for students to explore activities on their own through SketchUp Make's dynamic 3D modeling software. In the end, students can solve problems on their own, giving them space to think, training them to make their own decisions, and identifying possible mistakes throughout the learning process.

B. DIFFICULTIES IN VISUAL-SPATIAL SKILLS

The teaching and learning of geometry should be active and responsive beyond teacher's stimuli. In relation to that, students should be given the opportunity to conduct mathematical experiments through the exploration and investigation of their own geometric shapes [15]. Reference [16] believes that widespread exposure to the use of computer technology in mathematical visual-spatial is very helpful in geometry learning. Students' limited geometry experience does not provide an opportunity for them to construct and test VSS in geometry learning. This scenario may be due to the lack of educators who are skilled in using computers, dynamic software as well as the lack of basic knowledge of technology-based teaching and learning. Reference [15] claims that teachers need to optimise technological capabilities so that students can improve their understanding in mathematics. Therefore, technology-integrated modules should be encouraged in all school in order to improve students' skills that can meet the national needs of Malaysian Education Blueprint [17].

Many students are now exposed to indirect learning through the medium of information technology such as television and the internet [18]. Therefore, teachers need to have knowledge of computing and the internet to provide guidelines for their students. Motivation should be given to students when setting foot on the universities in the hope of acquiring good study skills, being able to find information, integrating current information technology with study skills, and becoming excellent graduates [11].

The teaching and learning of mathematics should use the latest technology to help students understand mathematical concepts in greater depth. Reference [15] explains that the use of calculators, technology, educational software, websites on the internet and related learning packages can help enhance pedagogical approaches and promote the understanding of mathematical concepts. The use of teaching resources will also help students absorb abstract ideas, become creative, feel confident and work independently or in groups. Most of these resources are designed for self-access learning. Through self-access, students will be able to access knowledge, skills and information independently according to their abilities. This desire stimulates students' interest and develops a sense of responsibility for their learning and understanding of mathematics.

[19] and [20] also explain that the effects produced by virtual objects are comparable to physical manipulation especially to geometry which is heavily focused on real-life exploration, problem solving, reasoning and applications. In relation to that, the paradigm has now changed in which dynamic geometry software now plays an important role in the teaching and learning of mathematics. Mathematics teachers now not only need to be firm in their knowledge of learning content, but also need to diversify their approach to delivery methods so that meaningful learning takes place. Following the development of information technology today, students are exposed to the sophistication of current communication technology such as WhatsApp, WeChat, Facebook, e-mail and many more applications. Therefore, teachers need to prepare themselves with knowledge of computer-based technology software that can help convey content knowledge in order to create fun learning in line with current students' technology skills.

In the teaching and learning process, computer is one of the technological equipments used [21] and processed by students. Through the process of analysis and exploration, students will obtain information such as facts, procedures, concepts and principles. If students are able to synthesize and explore the information through comparing and combining it with their initial knowledge, they will gain additional knowledge. Thus, the main task of teachers in the process of obtaining information is to assist students to analyze, synthesize and explore rational abilities related to generic evidence from teaching and learning materials [22].

In Malaysia, geometry is emphasized in the mathematics syllabus. However. there are many concepts of geometry presented to students that are unclear. Learning geometry becomes difficult because students and teachers are in different levels of thinking [23]. Imagination is required to learn geometry [24]. The lack of imagination causes students with learning disabilities to experience difficulties in VSS [25]. Therefore, teachers need to conduct meaningful geometry learning and provide opportunities for students to be active in constructing and developing concepts. The teaching and learning of mathematics no longer depends on existing descriptive methods and teaching aids. Recently, computer-assisted teaching and learning has been emphasized in the world of education. The use of computers in mathematics learning can change the approach to teaching and learning mathematics.

For the purpose of understanding a mathematical concept, students need different experiences such as iconic experiences. Iconic experiences refer to students' ability to use the mind to think of something and build a mental picture of an object or a situation that crosses their mind. Students will easily understand a mathematical concept through the use of concrete objects and sketches. Concrete materials are considered as a way to improve the understanding of mathematics [26]. They usually represent real objects used to represent many mathematical concepts [27]. Reference [28] shows that students of all ages can gains some benefits if they are introduced to mathematical concepts through physical exploration. With instructional planning ranging from pictorial concrete to abstract representations of concepts, mastery content becomes easier for students [29]. With concrete exploration through touching, seeing and doing, students can gain a deeper and more enduring understanding of mathematical concepts. Concrete materials are also seen as hands-on models that stimulate the senses and can be touched by students [30]. Teachers should select these materials in such a way as to relate to the real world of the students.

In order to gain an understanding of mathematics using concrete materials, students need to identify the mathematical concepts learned with the concrete materials used. Reference [31] shows that the use of concrete materials as an alternative teaching and learning can help teachers create a conducive classroom environment. Concrete materials can also serve as a motivational tool for students [32]. Reference [33] found that in lessons where concrete materials are used, students seem to have fun and they are actively involved. They understand concepts when they are actively involved in their own learning. They need to take control of their own learning and teachers need to provide them with opportunities to do so. Reference [34] supports the idea that concrete materials bridge the gap that separates how mathematics is taught and how mathematics is learned.

Advances in technology have undeniably helped the education system. In most developed nations, education has been penetrated by information technology [35]. Many teachers use computers and new technologies in teaching, while many textbooks have incorporated technology [36]. Most educators and researchers are trying to use new technologies, and this integration has changed the nature, concepts and methods of work in each subject [37]. For example, in mathematics, teaching and learning have changed with the use of technology [38]. In the past, mathematical concepts were traditionally taught using abstract and oral examples [39]. With the development of computer technology in recent years, the use of software has been able to redefine and simulate mathematical concepts [40].

In the past decade, research in software-assisted geometry learning has become so popular that it pushes away traditional learning that focuses on memorising lists of definitions and features of shapes. In general, some geometry researchers have suggested that geometry learning integrated with computer software is successful with an effort to improve VSS. Reference [13], [41]–[44] and [45] are among the previous researchers who have shown that students' VSS can be improved through learning modules integrated with computer software.

II. RESEARCH METHODOLOGY

The study was divided into two stages. Phase I focused on designing and developing SPPD-SUM, while Phase II tested the effect of SPPD-SUM on students' VSS. Stage I was guided by the instructional design model, i.e. ADDIE model which involved five phases, while Stage II was conducted using quantitative research methods to determine the learning effect of SPPD-SUM on improving VSS. The activities using the ADDIE model were Phase 1 (Analysis of important information), Phase 2 (SPPD-SUM Design), Phase 3 (Development of SPPD-SUM), Phase 4 (Implementation of SPPD-SUM) and Phase 5 (Evaluation of the effectiveness of SPPD-SUM learning strategies). Next, Phase II was conducted for six weeks through a quasi-experimental design involving a group of interventions with repeated data collection (single group time series design). The study involved 34 students, 20 females and 14 males. The students followed the traditional learning first for the chosen topic of Plan and Incentive. Thereafter, they were exposed to the intervention of learning through SPPD-SUM. A pre-test was conducted after the students followed the class traditionally, while repeated data collection (Pos1, Pos2, and Pos) was conducted immediately after the students followed the activities developed in OP1, OP2 and OP3. The PSVT: R and PSVT: V tests were used in this study. It was developed by Guay in 1977 and was contained in the Purdue Spatial Visualisation Test (PSVT). The characteristics of the question items were at a high level (the deduction level). The PSVT: R (Purdue Spatial Visualization Test: Rotation) test required respondents to mentally visualize the resulting 3D shape of a given 3D object that was rotated at a specific direction, magnitude of angle and axis. The test contained 30 items and each question began with a display of 3D objects before and after rotation, and followed by other 3D object questions that were not rotated. Five answers were provided that described the possible 3D shapes after being rotated according to the rotation of the 3D object. The PSVT: V (Purdue Spatial Visualization Test: View) test required the respondents to mentally visualize the resulting 3D shape according to a certain point of view from the display of a given 3D object. The test consisted of 30 items and each question began with a display of the 3D object to be depicted in a predetermined angle of view and was followed by five answers describing the shapes that might be depicted for the 3D object. The Mental Cutting Test (MCT) was developed in 1939 for university admission qualification in the United States [46]. This test was used to measure the ability to rotate an object mentally. There were 25 questions and each item started with a display of 3D objects clipped to specific parts and planes of the object. One cross-sectional view of the five answers described the cross-sectional result of the object after being cut into two parts. In addition to the spatial ability test recommended by [47], a test to measure the ability of the students to perform mental transformation (T3D2DT Test) was also used in this study. The T3D2D test was constructed by Mohd Safarin in 2009. Among the eight domains of transformation capability tested were top view orientation, front view orientation, right side view orientation, selection of view direction, visible and shielded parts, adjacent areas of different heights or depths, areas adjacent to the inclined surface, and the area adjacent to the cylindrical surface. This test contained 30 questions. Each question began with a display of a 3D object along with an arrow pointer for the direction of view. The respondents were required to mentally make a mental picture for the shape of the object surface viewed from a given viewing direction by selecting one correct answer from the five 3D object answers.

III. FINDINGS

Phase I of the study referred to the ADDIE model. The initial analysis found that the topic of Plans and Incentives needed to be focused with teachers and students expecting a more effective approach to aid learning and reduce reliance on memorization. In the second and third steps of designing and developing, the authors were assisted by two experienced mathematics teachers over 15 years and lecturers who were skilled in VSS and SketchUp Make software that developed activities in SPPD-SUM. Phases 4 and 5 were then conducted with validity assessment from experts consisting of five lecturers and two teachers with over 20 years of experience teaching mathematics. The findings of the pilot study found that SPPD-SUM was suitable for use in learning Geometry in the classroom. The findings of Phase II found that SPPD-SUM was significantly effective in improving students' VSS.

A. PHASE 1: SPPD-SUM DEVELOPMENT

The learning strategies developed in this study refer to the visual thinking model put forward by [48]. Reference [48] emphasized the interaction between images seen by the retina of the eye and those depicted in the mind box. The results were subsequently translated in the form of drawings. Recognizing the importance of visual-based learning and the learning objectives of this Geometry, we took steps to integrate and absorb the VSS Model presented by Kozhevnikov and his team [49]. The focused VSS consisted of four components, namely the ability to mentally rotate, the ability to view mentally, the ability to transform mentally, and the ability to cut mentally. This integration and absorption were done to ensure that the students could achieve better VSS by communicating and interacting physically and socially through the dynamic features of 3D modeling software SketchUp Make. SPPD-SUM consisted of three parts according to learning objectives (LO) known as LO1, LO2 and LO3 in which each LO contained four activities. The evaluation of validity tests by experts and pilot studies found that the SPPD-SUM was appropriate in terms of the validity of mathematical content and VSS. Among the interesting

TABLE 1. Distribution of instruments by phase of study.

Research Instruments		Purpose	Phase 2			
			Before		After	
			Pre	Pos_1	Pos_2	Pos
Spatial Ability Test	PSVT:R	To test the level of mental rotation ability	√	√	√	√
	PSVT:V	To test the level of ability to determine the view of an object viewed from a particular point of view mentally	√	√	√	√
	T3D2DT	To test the level of transforming ability mentally	√	√	√	√
	MCT	To test the level of cutting ability mentally	√	√	√	√

view by experts on SPPD-SUM was a new innovation of teaching 3D Geometry for the title of Plan and Incline. This method was easily understood by many students that fulfilled the mission and vision of teaching and learning Geometry of the 21st century. SPPD-SUM was also claimed to provide students the opportunity to use their own strategies and to encourage discussion during the learning process. Similarly, the analysis of student assessment in the pilot study found that SPPD-SUM was suitable for use in the classroom. They argued that page layouts, font sizes, pictures, charts, tables, texts and sentence instructions were easy to understand. Furthermore, step-by-step instructions were also easy to follow. As such, referring to the results of the experts and the students' validity assessment, it appears that SPPD-SUM was applicable in the classroom. This finding was gathered from a larger sample to answer the second question of this study. The next discussion explains the findings obtained to test the effect of SPPD-SUM on improving students' VSS.

1) RESEARCH INSTRUMENTS

In this study, the Spatial Ability Test instrument was used for the purposes shown in Table 1.

2) SPATIAL ABILITY TEST

The Spatial Ability Test for the VSS includes four abilities which are the ability to rotate, view, transform, and mentally cut. The question item to test this VSS component was an existing Spatial Ability Test and was based on the visual skills. The tests selected as part of the instrument were based on the instrument selection standard criteria recommended by [47] and the Mental 3D to 2D Transformation Test (T3D2DT) constructed by [7]. The basic considerations in selecting the standard of the instruments in this study were the validity, reliability, test administration procedures, scoring, and the cost of administering the test.

TABLE 2. Distribution of sub-test items for PSVT: R, PSVT: V and T3D2DT.

VSS Component	Sub-Test	Item No.	Test	Total Item
PSVT:R, PSVT:V and T3D2DT	A	1,4,7,10,13,16,19,22,25,28	Pre	10
	A	1,4,7,10,13,16,19,22,25,28	Pos1	10
	B	2,5,8,11,14,17,20,23,26,29	Pos2	10
	C	3,6,9,12,15,18,21,24,27,30	Pos	10

TABLE 3. Distribution of sub-test items for MCT.

VSS Component	Sub-Test	Item No.	Test	Total Item
MCT	A	1,4,7,10,13,16,19,22	Pre	8
	A	1,4,7,10,13,16,19,22	Pos1	8
	B	2,5,8,11,14,17,20,23	Pos2	8
	C	3,6,9,12,15,18,21,24,25	Pos	9

The Spatial Ability Test was used to identify the students' VSS by determining their ability scores that answered the questions in the four components of VSS, namely the ability to rotate, view, transform and mentally cut. This Spatial Ability Sub-Test was used to adapt to the time constraints of the respondents as there were four Spatial Ability Tests that required a long time to answer. This procedure also ensured that the questions used in each test were different but at the same time met the cognitive level, as conducted by [7]. The selection of the items of this Spatial Ability Sub-Test from the original test was systematically random, i.e., we selected the items according to the multiples of 3. The distribution of the items is shown in Table 2 and Table 3. Each item, if answered correctly, was given one mark. Next, the scores obtained were converted into percentage forms for analysis purposes. Thereafter, the Spatial Ability Achievement Level Table was referred to determine the VSS score, which was adapted from [47]. The test items conducted before and after the implementation of SPPD-SUM were of the same degree of difficulty.

a: PSVT:R SUB-TEST

To test the level of the students' ability to mentally rotate 3D objects, the PSVT: R Sub-Test was used. The respondents were allocated 10 minutes to answer the PSVT: R sub-Test. Each item, if answered correctly, was given one mark. Then, 10 marks were obtained if the students answered all the items correctly. An example of a PSVT: R question is shown in Figure 1.

To test the level of the students' ability to describe 3D objects from a mentally set point of view, the PSVT Sub-Test:V was used. Each item, if answered correctly, was given one mark. Then, 10 marks were obtained if the students answered all the items correctly. Examples of the PSVT:V test questions are shown in Diagram 2.

b: T3D2DT SUB-TEST

To test the students' ability to transform 3D objects to 2D, the T3D2DT Sub-Test was used. The time allotted was 10 minutes. Each item, if answered correctly, was given one mark. Hence, 10 marks were obtained if the students answered all the items correctly. Examples of the T3D2DT test questions are shown in Figure 3.

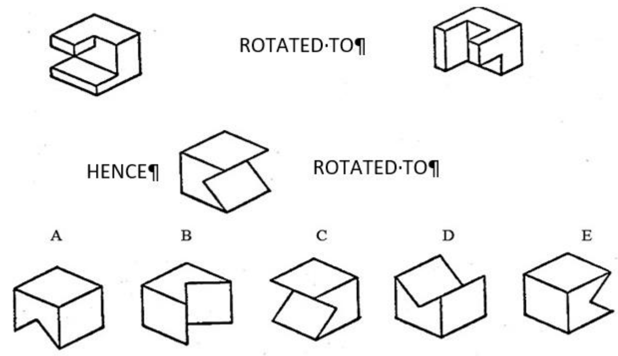


FIGURE 1. PSVT:R sub-test PSVT:V sample question.

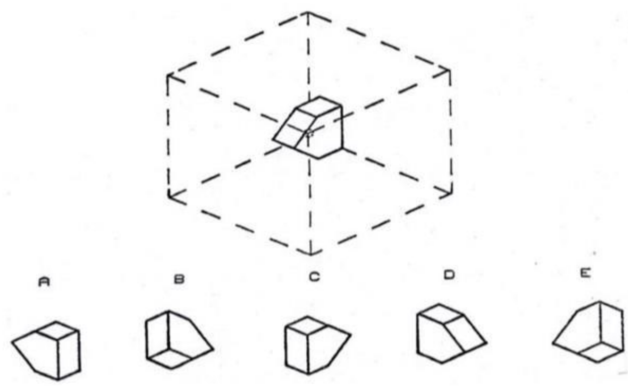


FIGURE 2. PSVT:V sample question.

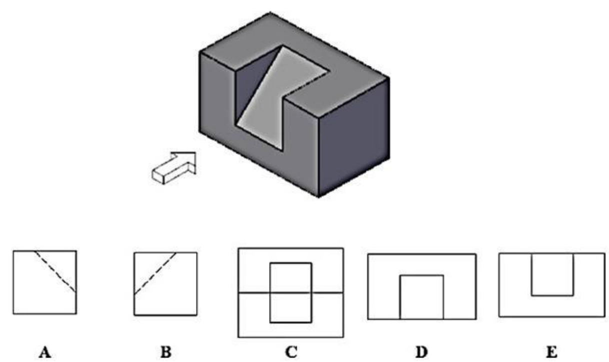


FIGURE 3. PSVT:V sample question.

c: MCT SUB-TEST

The MCT Sub-Test was used to test the level of the students' cutting ability mentally. The respondents were only allocated one minute to answer one question. One mark was given for each correct answer. Examples of the MCT test questions are shown in Figure 4.

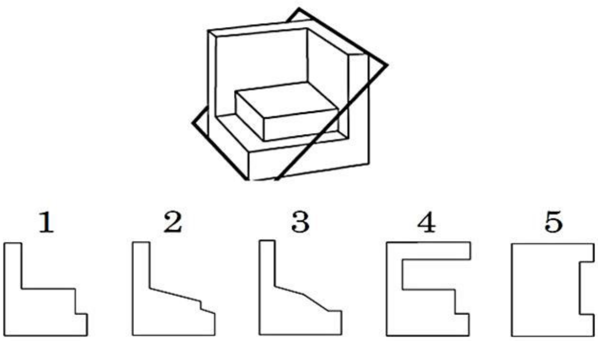


FIGURE 4. MCT sample question.

3) SELECTION OF SKETCHUP MAKE TOOLBAR TO TRAIN VISUAL-SPATIAL SKILLS

At this stage, the requirements of SketchUp Make in the development of SPPD-SUM were analysed logically and efficiently. The development of this learning strategy was based on the application of KVS through the dynamic 3D modeling software SketchUp Make. This combination was done to ensure that the students achieved the cognitive change, i.e., better VSS, by communicating and interacting physically and socially. The focused VSS consisted of four components, namely the ability to mentally rotate, view, transform and cut. The Toolbar on the SketchUp Make dynamic application used to help train the students' VSS in SPPD-SUM is shown in Table 4.

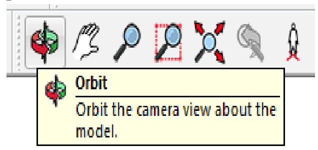
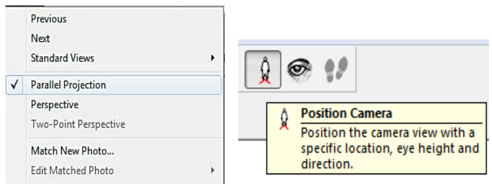
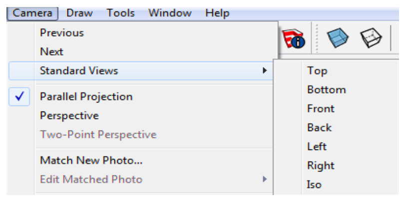
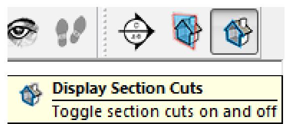
B. PHASE II: THE EFFECT OF SPPD-SUM ON STUDENTS' VSS

1) DATA ANALYSIS

The collected research data were then analysed with several approaches and methods to answer the research questions, which were the Stage II research questions. This SPPD-SUM effect analysis was conducted using a quasi-experimental design of one group pre-post test and a single-group time series design of a repeated measurement type for VSS. The quantitative data were analyszd using SPSS through descriptive and inferential statistical analyses.

The Level II quantitative data were obtained from the answers given by the students on the Spatial Ability Test for the four components of VSS. The quantitative data analysis involved descriptive and inferential analyses. The descriptive analysis displayed percentage values, means and standard deviations. After the descriptive analysis, the data were analyzed inferentially to examine the effect of SPPD-SUM on VSS. However, before the inferential analysis was carried out, the determination of the use of statistical assessment was first determined. Reference [50] explained that parametric and non-parametric inferential statistical approaches used in data analysis depend on the suitability and criteria of the data. The data from the VSS component test contained interval data. However, before the statistical parametric determination was used, there were several assumptions that needed to be

TABLE 4. Toolbar on the sketchup make which is used to train VSS.

VSS	Toolbar
Mental Rotation Ability	Orbit is used to perform rotational activities on the model to view projection lines and images on the displayed plane. 
Mental View Ability	The camera is set in Position Camera mode as well as in Parallel Projection mode to see solid corners more clearly. 
Mental Transformation Ability	The camera is set in Parallel Projection mode and Standard View is used to perform solid transformation activities from a specific surface point of view of the model to see the solid corners more clearly.  
Mental Cutting Ability	Display Section Cuts are used to see solid side cuts more clearly 

observed, among which the repeated measurement must be normally distributed.

According to [51] and [52], the uniformity test determines the normality of the distribution by using histogram graphs through Z-Skewness and Z-Kurtosis in the range −1.96 and +1.96 with the calculation of Z-Skewness and Z-Kurtosis values. In this study, before the MANOVA inference test or one-way ANOVA for repeated measurements was carried out, there were other assumptions that must be observed, namely the similarity of variance (Homogeneity of variance) and the similarity of covariance (Homogeneity of Covariance). Therefore, in addition to ensuring that the similarity of variance was observed, the covariance that compared the deviation from the overall mean must also be met. For the test of similarity of variance (Homogeneity of variance), [53] explained that it could be identified using a Levene test. The insignificant results of the Levene test ($p > 0.05$) showed that the data met this assumption. Meanwhile, [54] explained that the assumption of homogeneity of the same covariance for each level of within-subjects variables for repeated measurement designs is known as Sphericity. This assumption explains that if a new variable is created from each pair of variables within the subjects of the same person, the scores obtained will be the same. However, there is a lack of behavioral science data that meet the Sphericity assumption, and non-compliance with this assumption is serious and can affect results. However, [54] explained that there is a good way to overcome this problem, i.e., by adjusting the degree of freedom or by using a multivariate approach to repeated measurements.

Sphericity assumption can be tested using the Maunchly test, Box Test, Greenhouse-Geisser test, and/or Huynh-Feldt test. If the estimated epsilons value for the level of Sphericity in the population is less than 1.0, it indicates that the assumption of Sphericity is not observed. Lower-bound indicates the lowest value for epsilon and the highest epsilon value is always 1.0. When Sphericity is not observed, multivariate results or values of epsilons are used to adjust the numerator and denominator of dfs. Typically, when the epsilons value < 0.75, the Greenhouse-Geisser epsilon value is used, but Huynh-Feldt is used if the epsilon > 0.75.

2) VISUAL-SPATIAL SKILL (VSS)

Data for VSS for each student were obtained from four VSS component tests, namely PSVT:R for mental rotation ability, PSVT:V for mental view ability, T3D2DT for mental transformation ability, and MCT for mental cutting skills, as follows:

$$VS = PSVT:R + PSVT:V + T3D2DT + MCT\,4$$

Data were gathered by repeated measurements through Pre, Pos1, Pos2 and Pos tests referring to three learning objectives in which each learning objective involved four activities. Pre-tests were given after the students followed traditional learning, while Pos1, Pos2 and Pos tests were given immediately after undergoing the intervention. However, the main analysis only involved the data from Pre and Post tests, while the data from Pos1 and Pos2 tests were used as supporting data for an in-depth discussion of the findings obtained.

The quantitative data analysis is shown in Table 5, following a score interpretation for the VSS mastery level based on a VSS test score by [47] in Table 6. Next, the descriptive analysis was used to obtain percentage, mean, and standard deviation values, while the inferential analysis was applied in order to compare the mean scores of the Spatial Ability Test before and after the intervention. The students answered the scripts in the pre test, Pos1 test, Pos2 test and Post test for the Spatial Ability Test that was checked and evaluated by the researchers. The raw scores from the interval

TABLE 5. Quantitative data analysis according to research questions for the sixth.

What is the effect of SPPD-SUM in helping students improve:	Instrument	Analysis Method	Statistics
i. VSS?	Spatial Ability Test: PSVT:R PSVT:V T3D2DT MCT	Descriptive	Mean and percentage
		Inferential	- Paired t-test - Manova Repeated Measurement Test
ii. VS Component?		Descriptive	Mean and percentage
		Inferential	- One Way Anova - Repeated Measurement Test

TABLE 6. Interpretation of scores for VSS mastery level based on VSS score.

Marks Score (%)	Spatial Ability Test Score Level	KVS Mastery Level
80-100	Above average score	Excellent
60-79	Average score	Good
40-59	Little below the average score	Moderate
0-39	Below average score	Low

data obtained by each student in each test were converted to percentages using SPSS.

Next, an analysis of the percentages in VSS scores was conducted. Subsequently, the descriptive statistics of the scores based on the VSS level before and after the intervention was referred to a score interpretation for the VSS mastery level in Table 6. In order to see the VSS improvement more clearly, the data were presented in the form of graphs before and after the intervention. For this purpose, the students were categorised according to the VSS mastery level cohort by referring to the Pre-test findings. Furthermore, to prove that there was a difference in mean values before and after the intervention, the inferential statistics of Paired Sample t-test was conducted. A significant difference was obtained if $p < 0.05$. However, the normality test needed to be first adhered to.

Next, the inferential analysis of the MANOVA test for repeated measurements was conducted to identify the effect of the intervention on each VSS component. Therefore, normality tests and homogeneity tests for repeated measurements should also be carried out first. Significant differences between pre-test and post-test data for each KVS component were obtained if $p < 0.05$. To support the above findings, the analysis was continued by looking more deeply at the improvements that occurred throughout the learning interventions in OP1, OP2, OP3. A one-way ANOVA inferential analysis test was conducted to see if significant differences occurred throughout the intervention in SPPD-SUM learning. Prior to that, normality tests were interpreted. After that, the results of Maunchly's Test of Sphericity were referred. If the range was opposite (assumption of sphericity was violated), i.e., the value of $p < 0.05$ was significant, the

TABLE 7. Interpretation of scores for VSS mastery level based on VSS scores.

Study Phase	Study Sub-Phase	Sampling Method	Study Sample	Size of Sample
Phase I	Analysis Phase	Purposeful Sampling	Experienced Mathematics teachers and students	*n* Teacher =3 *n* Student =3
	Pilot Study Implementation Phase I	Volunteer	Students	*n* =12
	Pilot Study Implementation Phase II	Volunteer	Students	*n* =12
Phase II	Quantitative	Purposeful Sampling	A student intervention group	*n* =34

value of epsilon (F) should be seen to modify the value of F (degree of freedom). A significant percentage difference of KVS component scores was obtained when the p value <0.050. The results of the comparison test in the subject (Test of Within-Subject Contrast) showed that the comparison between the interventions (i.e., Pre-Pos1, Pos1-Pos2 and Pos2-Pos) was significant when $p < 0.05$.

Next, [54] proposed to see the extent to which the effect size (eta^2) value of Partial Eta Squared obtained directly in this analysis was referred according to the categories outlined by [55], as follows:

< eta2 < 0.1: Small or smaller than usual
< eta2 < 0.24: Medium or normal
0.24 < eta2 < 0.37: Big or bigger than usual
eta2 > 0.37: Bigger than usual.

3) STUDY SUBJECT

In this study, the sample involved was form-five students who, according to [56], were in the projective stage of VSS. In other words, these students possessed the ability to visualize 3D objects from different directions, angles or points of view, rotated or incarnated in spatial. In addition, experienced teachers and lecturers were also involved in this study. However, their involvement occurred at the analysis and evaluation phases only. The teachers were selected based on their professional qualification and the duration of experiences in teaching mathematics. The lecturers were selected based on their expertise in the domain of validity assessed, as shown in Table 7.

C. SUMMARY OF DATA ANALYSIS AND PRESENTATION OF FINDINGS

In order to achieve the objectives of the study, we evaluated the effect of SPPD-SUM on students' VSS. The analysis was conducted on two main constructs, namely the effect of SPPD-SUM learning intervention on students' VSS. The analysis for VSS refers to two types of data, namely the overall score of VSS and the score of each component in VSS. The analysis for both data sets involved a quantitative analysis, i.e., descriptive and inferential analyses. Before the inferential analysis was performed, the determination of the use of statistical assessment was determined first. Parametric and non-parametric inferential statistical approaches were used in data analysis depending on the suitability and criteria of the data that need to be met. The data from the VSS component test were analyzed using statistical parametric because the data was interval. The results of the uniformity test using histogram graph display Z-Skewness and Z-Kurtosis in the range of −1.96 and +1.96 are said to be normally distributed. However, before the MANOVA inference test or one-way ANOVA for repeated measurements was carried out, there were other assumptions that needed to be observed, namely the similarity of variance (Homogeneity of variance) and the similarity of covariance (Homogeneity of Covariance). Homogeneity of variance test using a Levene test showed that the results were not significant ($p > 0.05$), indicating that the data met this assumption. Meanwhile, for homogeneity of Covariance, the Sphericity assumption was tested using the Maunchly test, the Greenhouse-Geisser test, and/or the Huynh-Feldt test. When Sphericity was not observed, multivariate results or values of epsilons were used to adjust the numerator and denominator of dfs. Typically, when epsilons values <0.75, Greenhouse-Geisser epsilon values were used, but Huynh-Feldt was used if epsilon >0.75, which is discussed along with the findings.

D. RESULTS OF ANALYSIS OF DIFFERENCE IN MEAN PERCENTAGE OF STUDENTS' VISUAL-SPATIAL SKILLS SCORE BEFORE AND AFTER THE INTERVENTION

This section presents the findings of the analysis for students' VSS before and after the intervention, i.e., SPPD-SUM learning. The percentage score for the VSS component test obtained from each of the correct answers was given one mark. Next, the scores obtained were converted into percentage forms for analysis purposes. Thereafter, the Spatial Ability Level Table was referred to determine the level based on the scores obtained by the students, which was adapted from [47].

To see the comparison of Pre- and Post-test findings more clearly, the data were collected in class intervals, as shown in Table 8. As can be seen, the pre-test frequencies are distributed in class intervals below the class interval 61-70, while the post-test frequencies are distributed at class intervals 61–70 and above. Similarly, it was found that the Pre-test mode class is at a class interval of 31–40, while the Post-test mode class jumps to a class interval of 71–80 with the number of mode frequencies also increasing from 14 to 17. Next, the change for the percentage distribution of scores for the Pre-Post tests is presented more clearly through the Polygon Frequency graph, as shown in Figure 5.

A clear improvement can be observed in the Post-test result in which the percentage distribution of scores after the intervention is between the interval 65.5 to 95.5, whereas previously, the percentage distribution of scores is between

TABLE 8. Frequency distribution of percentage score for VSS before and after intervention.

Score Percentage	Pre-Frequency	Post Frequency
21-30	4	0
31-40	14	0
41-50	6	0
51-60	7	0
61-70	1	6
71-80	0	17
81-90	0	8
91-100	0	3

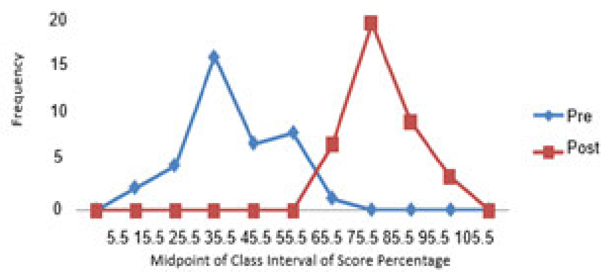


FIGURE 5. Distribution of percentage score for VSS before and after intervention.

TABLE 9. VSS descriptive statistics before and after the intervention.

VSS	Mean	Standard Deviation	Standard Error Mean
Pre	39.8	12.0	2.1
Post	78.4	8.8	1.5

the interval 15.5 to 65.5. It can also be seen that there is an overlap of scores in the Pre- and Post-tests, which is a score of 65.5. There is a possibility that the same students are on the same score or, in other words, there is no increase or there may also be a decrease in the percentage of scores. An explanation for this possibility will be discussed in the difference in percentage scores before and after using SPPD-SUM individually. Next, the results of this analysis are further clarified by Table 9 which displays the descriptive statistics of VSS before and after the intervention. It was found that VSS after the intervention (mean = 78.4) is different before the intervention (mean = 39.8). Moreover, the difference in standard deviation values after the intervention is smaller compared to that before the intervention. In other words, the scores after the intervention are closer to the average percentage score as compared to those before the intervention.

The difference in mean value is further clarified by the inferential analysis test of paired sample t-test. Prior to that, results of the normality tests display values of $-1.96 <$ Z-Skewness Pre $= 0.5$ and Z-Skewness Post $= 1.62 < +1.96$, indicating that the skewness of the data is symmetrical or normally distributed. Next, the calculations reveal the values of $-1.96 <$ Z-Kurtosis Pre $= -0.35$ and Z-Kurtosis Post $= 0.25 < +1.96$, indicating that the data are mesochurtic or normally distributed. Thus, normality is met. Subsequently, a paired sample t-test was conducted to confirm whether there were significant differences in the scores before and after the intervention. Referring to Table 10, the results of the analysis show that there is a significant difference in the mean score of VSS before and after the intervention ($t = 35.47$; $p < 0.05$).

To determine the extent to which the mean differed before and after the intervention, an effect size test via Cohen's formula d was performed. Referring to the value of $d = 3.7 > 0.8$ obtained, it can be argued that the mean percentage difference of scores before and after the intervention falls in the large category. In conclusion, the results of the findings suggest that the intervention can improve the percentage of VSS scores among the students involved in this study. In addition, the findings of the study also show that the mean percentage scores differ significantly before and after the intervention with a very large effect size.

The next analysis explains the percentage increase in VSS scores. Table 11 displays the change in students' VSS scores before and after the intervention.

Table 11 shows the lowest percentage score of 26.3 to the highest percentage score of 56.3. It can be observed that the minimum and maximum percentage values of VSS scores before the intervention are 15.0 and 66.5, respectively The scores increase after the intervention with minimum and maximum percentage scores of 64.0 and 100, respectively. In addition, the VSS scores before and after the intervention decrease from 51.5 to 36.0 (a decrease of 15.5). These findings show that the inter-individual difference gap in VSS is getting smaller after the intervention. It can also be observed that the minimum value of the percentage score for the Post-test is below the maximum value for the Pre-test. Hence, the question arises whether there is a possibility that the students' percentage scores remain the same or whether the percentage scores decrease after the intervention. This question is addressed through the results that show a percentage increase of 38.5 in which the lowest percentage increase is 26.3 while the highest percentage increase is 56.3. In other words, there is no decrease in percentage scores.

The subsequent discussions explain the changes of VSS levels that occur before and after the intervention. For this purpose, the students' VSS levels are classified according to the four-category convention by referring to the score interpretation for the VSS mastery levels by [47], as shown in Table 12 for the achievement in the Pre-test. Accordingly, referring to Table 13, it can be seen that, out of 13 students, the number of students who are at low and moderate levels after the intervention is reduced to 2 students only.

This positive increase is evident with 11 students scoring at the excellent level. It is worth noting that none of the students are at this level before the intervention. In line with these findings, it can be observed that the mean percentage scores obtained by the students for each level increase as a whole, especially the average level score of 50.6 to 79.3 and the good level score of 66.5 to 72.9.

TABLE 10. Paired sample t-test for VSS before and after the intervention.

VSS	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Post - Pre	38.5	6.3	1.1	40.8	36.3	35.5	33	.000

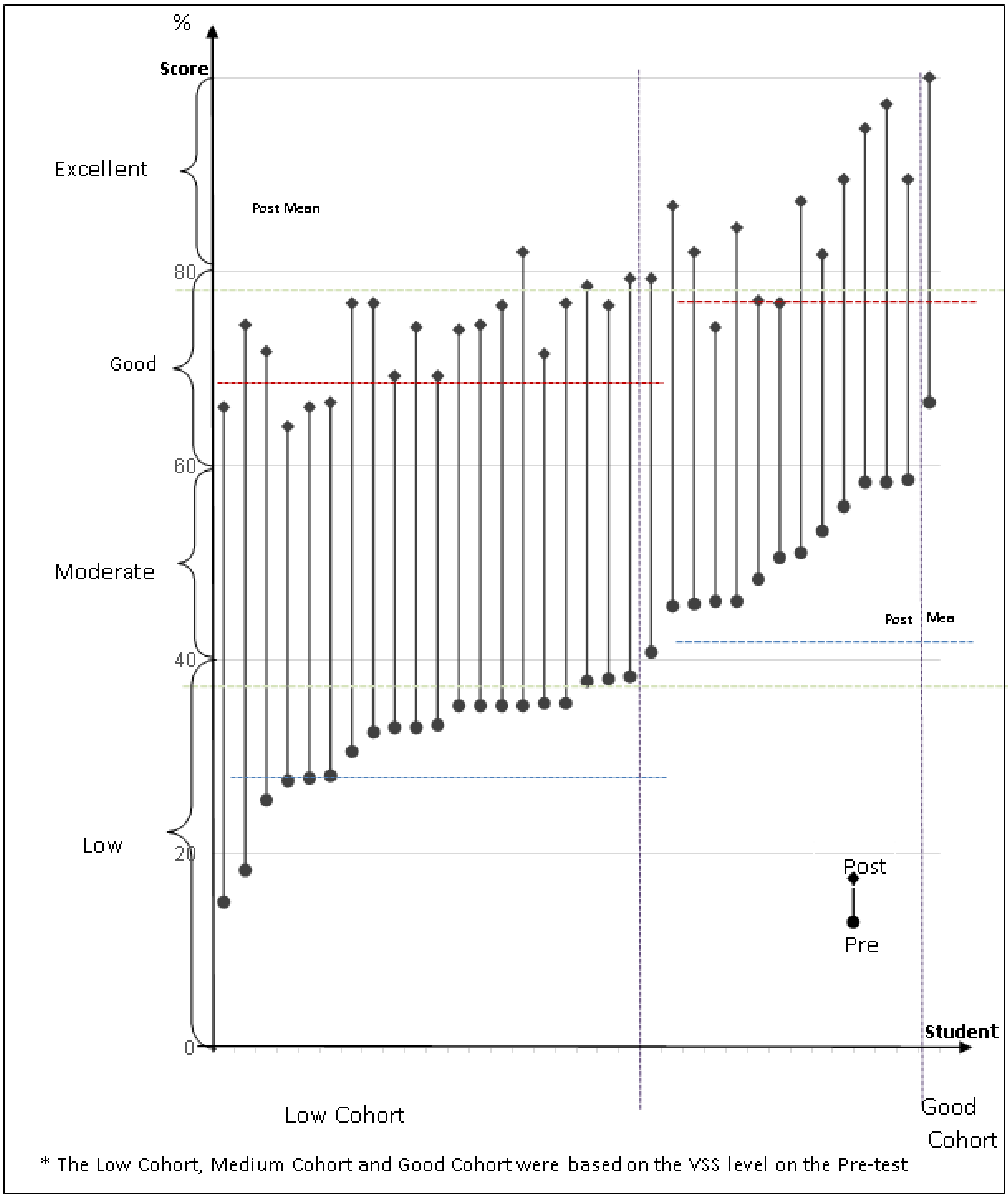


FIGURE 6. Percentage increase in individual student VSS scores before and after the intervention.

To see the positive effect of this intervention on all samples involved, the discussion continues with the results of VSS improvement in Figure 6. In this case, the students are categorised into three level cohorts, namely low, moderate and good cohorts by referring to the students' VSS levels in the Pre-test based on Table 12.

It can be seen that the order of increase in the percentage of VSS scores is based on the percentage of the lowest score during the Pre-test (i.e., 15.0 obtained by P33) to

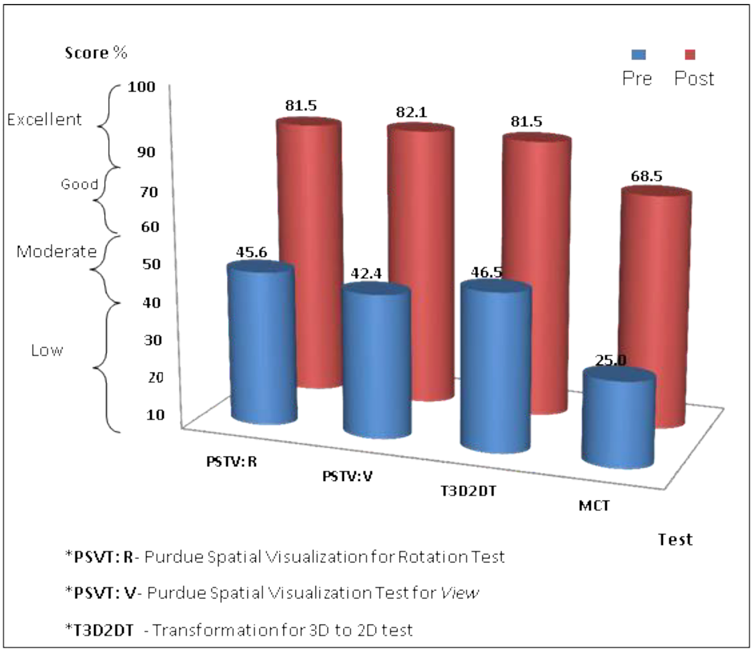


FIGURE 7. Mean percentage score difference of each VSS component before and after the intervention.

TABLE 11. Increase in VSS percentage scores before and after the intervention.

	VSS Percentage Scores		
	Pre % Score	Post % Score	Score Increase
Minimum	15.0	64.0	26.3
Maximum	66.5	100	56.3
Mean	39.8	78.4	38.5
Range	51.5	36.0	30.0

TABLE 12. Convention of the four categories of students' VSS levels.

Mark Score (percentage)	Score Level	Level	Cohort
80-100	Above average score	Excellent	Excellent Cohort
60-79	Average score	Good	Good Cohort
40-59	Little below the average score	Moderate	Moderate Cohort
0-39	Below average score	Low	Low Cohort

TABLE 13. Descriptive statistics of score percentage based on VSS levels before and after the intervention.

VSS Level	Pre				Post			
	N	Mean % Score	Min % Score	Max % Score	N	Mean % Score	Min % Score	Max % Score
Low	20	31.3	15.0	38.3	0	0	0	0
Moderate	13	50.6	40.8	58.5	2	79.3	79.3	79.3
Good	1	66.5	66.5	66.5	21	72.9	64.0	78.5
Excellent	0	0	0	0	11	88.7	81.8	100
Overall	34	15.0	66.5	39.8	34	78.4	64.0	100

the percentage of the highest score (i.e., 66.5 obtained by P6). A positive improvement can be clearly observed after the intervention when most students obtained more than 60.0 percent score in the Post-test. Furthermore, it can be seen that the distribution of the Post-test data is closer to the mean of Post compared to the distribution of the Pre-test data with the mean of Pre. In addition, three students, i.e., P33, P20 and P6 (over 20 percentage scores) move away from the Pre mean line compared to only one student (i.e., P6) in the Post-test data. In other words, the interventions can narrow the gap between individuals especially among low-income groups.

This trend is supported by the decreasing gradient in the linear line formed in the Post-test for the low cohort. In addition, it can also be observed that the students who obtain a low percentage score in the Pre-test (i.e., P3 and P20) manage to compete with other students in the Post-test with a percentage score exceeding 50 percent and approaching the mean percentage score in the Post-test. Next, it can also be observed that P6 obtains a full percentage score of 100 in the Post-test. For a more in-depth explanation for this improvement, the achievement for Pos1 and Pos2 tests for some students is shown in Table 14. It can be observed that the students' improvement is gradual across the tests conducted.

The discussion is now continued with a qualitative analysis. Our observations on the entire sample show seriousness throughout the learning process, especially in the Independent Orientation Phase. This positive behavior was evident when the students made full use of the dynamic features available in the SketchUp Make software throughout the learning process in the SPPD-SUM. In addition, it was

TABLE 14. Percentage increase of students' VSS score in Pre-Pos_1-Pos_2-Post test.

Student	Pre	Pos_1	Increase in Score%	Pos_2	Increase in Score%	Post	Increase in Score%
P33	15.0	37.8	22.8	53.3	15.5	66.0	12.8
P1	35.3	58.5	23.3	74.3	16.8	82.0	7.8
P6	66.5	89.5	23.0	97.3	7.8	100	2.8
P13	58.3	76.5	18.3	84.3	8.0	97.3	12.8

observed that the students initiated discussions during the Independent Orientation Phase and the knowledge sharing session. Moreover, when the Pos1, Pos2 and Pos tests were conducted, the students seemed to move the object using hand gestures in depicting the 3D object. The time taken to complete the given question was getting faster across the given test.

In conclusion, based on the descriptive and inferential analyses discussed above, it can be suggested that learning using SPPD-SUM can enhance the VSS of the students involved. The next section explains the effect of the intervention on each component of VSS.

E. RESULTS OF ANALYSIS OF MEAN PERCENTAGE DIFFERENCE FOR EACH COMPONENT OF STUDENTS' VISUAL-SPATIAL SKILLS BEFORE AND AFTER THE INTERVENTION

The VSS component in this study refers to the ability to mentally rotate, view, transform and cut. Furthermore, the effect of the intervention on each VSS component is also discussed. As mentioned earlier, this discussion involves the improvements that occur in each component of VSS involving the Pre-test and Post-test. Figure 7 displays the mean percentage score differences for each VSS component before and after the intervention. The results show that the intervention has successfully improved the mean percentage score of all VSS components with the highest difference obtained by mental cutting ability. In this context, the mean percentage of Pre-test score = 24.9 has originally increased to Post-test = 68.5 with a percentage score increase of 43.6. It can also be observed that the intervention has increased the level of mental cutting to a good level. The ability to rotate, view and mentally transform has also increased from a moderate level to an excellent level.

Furthermore, inferential analysis of the MANOVA test for repeated measurements was conducted to identify the effect of the intervention on each VSS component. Thus, the normality test and the Levene test were performed first. The results are as follows: For the Pre-Post data for PSVT:R value ($-1.96 <$ Z-Skewness Pre $= -0.45$ and Z-Skewness Post $= -0.76 < +1.96$), PSVT:V value ($-1.96 <$ Z-Pre Skewness $= 0.01$ and Z-Skewness Pos $= -0.11 < +1.96$), T3D2DT values ($-1.96 <$ Z-Skewness Pre $= 0.086$ and Z-Skewness Pos $= -0.41 < +1.96$) and MCT values ($-1.96 <$ Z- Pre-Skewness $= 0.00$ and Post Z-Skewness $= 0.21 < +1.96$). The Pre-Post data skewness for PSVT:R, PSVT:V, T3D2DT and MCT is symmetrical or normally distributed. Next, the calculations for Pre-Post data for PSVT:R, PSVT:V, T3D2DT and MCT, obtained values of $-1.96 <$ Z-Kurtosis Pre $= 0.46$ and Z-Kurtosis Post $= -0.76 < +1.96$, $-1.96 <$ Z-Kurtosis Pre $= -0.76$ and Z- Kurtosis Post $= -0.95 < +1.96$, $-1.96 <$ Z -Kurtosis Pre $= -0.721$ and Z -Kurtosis Post $= -0.595 < +1.96$ and $-1.96 <$ Z -Kurtosis Pre $= -0.36$ and Z -Kurtosis Pos $= 0.09 < +1.96$, indicating that the Pre-Pos data for PSVT: R, PSVT:V, T3D2DT and MCT are mesocurtic or normally distributed. In addition, the Levene test results are not significant for PSVT:R [Pre ($p = 0.11$, Post ($p = 0.38$)], PSVT:V [Pre ($p = 0.61$, Post ($p = 0.38$)], T3D2DT [Pre ($p = 0.60$, Pos ($p = 0.22$)] and MCT [Pre ($p = 0.73$, Pos ($p = 0.07$)], showing that the variance values are the same for each pre- and post-test across each VSS component. The conditions for repeated measurement MANOVA tests were then carried out.

Furthermore, the Multivariate Pillai's Trace test, as shown in Table 15 above, reveals that there is a significant primary effect of the Pre-Post variable [$F(4,30) = 332.5$, $p < 0.05$]. This means that, overall, there are significant differences between the pre-test and post-test data for each VSS component. Subsequently, the Univariate test further shows that there is a significant Pre-Post effect on all four components of VSS, namely PSVT:R [$F(1,33) = 359.0$, $p < 0.05$], PSVT:V [$F(1,33) = 347.0$, $p < 0.05$], T3D2DT [$F(1,33) = 357$, $p < 0.05$] and MCT [$F(1,33) = 590.5$, $p < 0.05$]. Based on these results, it can be claimed that the intervention is significantly effective in increasing the ability to rotate (mean: Pre = 45.6, Pos = 81.5), to view (mean: Pre = 42.4, Pos = 82.1), to transform (mean: Pre = 46.5, Pos = 81.5) and to cut mentally (mean: Pre = 24.9, Post = 68.5). In addition, the shape of the high PSVT:R, PSVT:V, T3D2DT and MCT line graphs next to the Pos test (right) in Figure 8 clearly shows that the intervention improves the ability to rotate, view, transform, and mentally cut the study sample.

Based on the results discussed above, it is evident that the intervention can effectively enhance the students' ability to mentally rotate, view, transform and cut.

F. SUMMARY OF THE FINDINGS OF THE STUDY

The initial findings of this study found that more than 50% of the students obtained a percentage score below 40 with an average percentage of 39.8, which is at a weak VSS level. It can be interpreted that the students in this study had a moderate level of ability to mentally rotate, view and transform with average percentage scores of 45.6, 42.4 and 46.5, respectively. Moreover, the mental cutting ability of the students was found to be very weak with an average percentage score of only 25. Furthermore, the findings obtained from the descriptive analysis show that the distribution of scores has increased after learning through SPPD-SUM in which the majority of the scores are at over 70 %, with 32 % of the students reaching an excellent level. In addition, the improvement of the students' VSS was

TABLE 15. Multivariate pillai's trace test MANOVA test for repetitive measurements.

Effect			Value	F	Hypothesis df	Error df	Sig.
Between Subjects	Intercept	Pillai's Trace	1.0	302.2	4	30	.000
		Wilks' Lambda	0.0	302.2	4	30	.000
		Hotelling's Trace	40.3	302.2	4	30	.000
		Roy's Largest Root	40.3	302.2	4	30	.000
Within Subjects	Pra-Pos	Pillai's Trace	1.0	332.5	4	30	.000
		Wilks' Lambda	00.0	332.5	4	30	.000
		Hotelling's Trace	44.3	332.5	4	30	.000
		Roy's Largest Root	44.3	332.5	4	30	.000

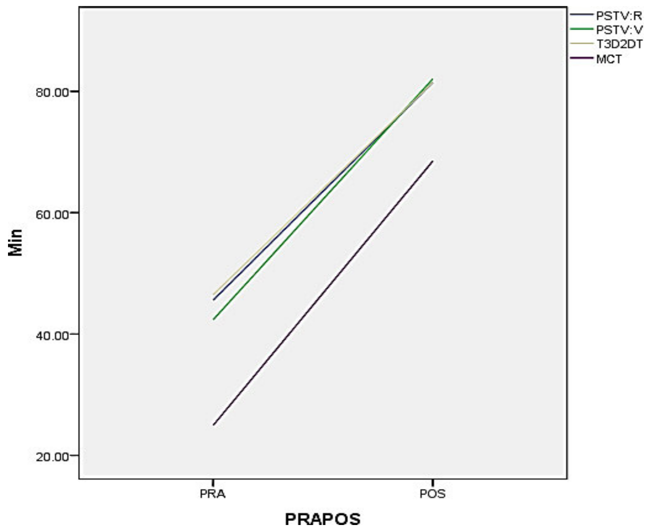


FIGURE 8. Line graph for PSVT:R, PSVT:V, T3D2DT and MCT.

statistically verified by a paired t-test inferential analysis. The results display a significant difference in VSS after learning through the SPPD-SUM with an increase in the overall percentage score to 78.40 and also with a very large effect (d = 3.7). A more detailed analysis of the findings shows that the students' ability to mentally rotate, view and transform has increased to an excellent level, while the cutting ability has increased to a good level. This improvement is evident in the MANOVA analysis that shows significant differences before and after the intervention. Subsequently, the changes occurring to the ability to rotate, view, transform and cut individually after the intervention using a one-way ANOVA of repeated measurements show a significant improvement across repeated tests.

IV. DISCUSSION OF THE FINDINGS OF THE STUDY

A. DEVELOPMENT OF SPPD-SUM

The learning strategy developed over almost nine months in the current study fully applies the ADDIE development model of analysis, design, development, implementation and evaluation. The learning topic chosen in this study was Plan and Elevation, which is a Geometry topic that involves space and shape. The use of the dynamic 3D modeling software SketchUp Make greatly helps in realising the combination of VSS capabilities. The special feature of the dynamic feature in SketchUp Make enables the students to rotate the object, to look at the object from every angle, to transform the 3D object to 2D with the set view direction, and also to cut the 3D object on the screen display [43].

After learning this topic, the students are expected to have a good VSS, as outlined by [57]. In other words, the activities developed through the dynamic 3D modeling software SketchUp Make can successfully train the ability to mentally rotate, view, transform and cut 3D objects. Yet, the initial findings of the study show an unexpected trend. Once learning is traditionally conducted, the results show that the majority of the students have a poor VSS. To overcome this problem, the activities in SPPD-SUM were planned and developed carefully by integrating and absorbing VSS through the dynamic 3D modeling software SketchUp Make.

It appears that these positive findings were obtained from a learning strategy that integrates VSS through the dynamic 3D modeling software SketchUp Make. Moreover, the learning strategy is in line with the visual thinking put forward by [48]. This visual thinking is embodied through three elements of visual imagery. First, students see 3D objects on a computer through the dynamic 3D modeling software SketchUp Make. Second, students see an imagery that can be pictured or imagined in the mind box in the conscious state. Third, the shadow of the imagery is translated into a drawing or a sketch. Previous studies by [58], [9], [59] and [7] have shown the successful use of this model in CAD-based teaching and learning.

B. IMPROVING STUDENTS' VISUAL-SPATIAL SKILLS

The preliminary findings of the current study reveal that the majority of the students' visual skills are in the weak category. That is, the ability to rotate, view and transform is in the moderate category, while the ability to mentally cut is in the weak category. Based on a spatial visualization test conducted at an early stage, reference [5] found that the VSS for 53 students is low in which only 19 of them reach the high ability. In a preliminary study on VSS among engineering students in a technical school in Johor, reference [60] found that only a few students are at an excellent level, with the ability to cut mentally being the most difficult ability to master. In addition, reference [61] examined the students at Technical Secondary Schools in Johor and found a moderate level of visual perception, a high level of visual memory, and a low level of visualization. Similarly, reference [62] found that the level of visual skills of rotation and combination is at a moderate level, while the level of combination skills is at a moderately high level.

As such, the question arises whether successful teaching and learning can be carried out by expecting students to visualize a given 3D object, especially in the title Plans and Incentives. However, the 3D object displayed in the question is in the form of a 2D orthographic display in which students have to imagine the 3D object mentally. That is, they have to perform rotation, view, transform, and cut the object mentally according to the requirements of the question. However, this weakness is not highlighted on the grounds that students do not have problems answering MCE formatted questions based on the analysis of examinations each year. However, the reality is that the questions given have a similar format. Furthermore, the success of the drill questions of previous years and the MCE formatted questions managed to give a short-term memorization effect for students to expect 2D shapes from a given 3D object. The issue arises as to whether the learning objective is only for students to successfully answer questions at the MCE level only. This does not help students in training their VSS. The problem will start to surface when they venture into the fields of higher education that require a good VSS.

After the SPPD-SUM intervention, the average VSS of the students in the current study was found to increase. In detail, the students' ability to mentally rotate, view, and transform has increased to an excellent level, while the cutting ability has increased to a good level. We believe that the students' mental cutting ability will increase to an excellent level with continuous spatial training, as suggested by [63] and [64]. Interestingly, in addition to improving the overall VSS of the students, the distribution of students' scores is closer to the mean value of the overall score percentage. In other words, learning through SPPD-SUM has succeeded in narrowing the gap between the achievements of individual students involved in this study. The success of a learning technique is measured not only by the increasing number of excellent students, but also by being accepted and applied by all students, as recommended by the Ministry of Education Malaysia in the initial report of Malaysian Education Blueprint [PPPM] (2012).

In addition, the findings show an increase of individual improvement, as shown in Figure 5.5. Based on these findings, it is clear that learning through SPPD-SUM can successfully enhance the students' VSS. That is, students' VSS can be trained, in line with the findings of [7]. These findings accord well with the findings of the previous Geometry researcher [65] who claims that dynamic software can improve students' VSS. He qualitatively narrates the process of positive cognitive change among students after using dynamic software. In addition, reference [42] investigated the effect of SketchUp Make software on the VSS of high school students. The results on spatial and mental rotation test (MRT) before and after the application show that the VSS scores increase significantly after the implementation. Reference [41] explored the impact of the SketchUp Make 3D Modeling programme on the spatial abilities of grade 8 students through an experimental design. The results show that VSS increased after the intervention was carried out.

The current study is in tandem with [43] who have constructed activities using SketchUp Make to increase the spatial abilities of undergraduate students. However, their study only focuses on the ability to rotate mentally and spatial orientation (view) only. In addition, [44] conducted an experimental study using a web-based virtual environment to enhance teachers' pre-service spatial capabilities. Their study was conducted through a computer-assisted course that lasted for five weeks. Training was given and spatial tests were used. The results show that the overall spatial ability of the participants increased significantly. Similarly, [66] investigated the effect of SketchUp Make based on Geometry activities on the VSS of prospective mathematics teachers. The results show a positive effect on VSS between treatment groups. Moreover, previous studies have also shown positive effects of virtual and map-based tours [67], virtual reality applications [68], [69] and spatial games [45].

The latest finding was discovered by [13] using van Hiele's learning phase-based learning strategy through SketchUp Make software. The findings show that learning through SketchUp Make software helps students improve their visual imagery abilities. In addition, the conceptual and procedural knowledge of Geometry has also increased. These findings are also found to be consistent with the findings of several researchers in the field of Engineering Drawing using other dynamic modeling software such as AUTOCAD and Cabri 3D. Reference [7] conducted a study on form-four students at a Technical Secondary School in Johor Bahru using Engineering Drawing through AUTOCAD 3D modeling software. He found that the students faced a problem in VSS and managed to overcome it with AUTOCAD software-assisted learning. Similarly, [70] and [71] also found that sketching methods and the integration of 3D modeling in learning have successfully improved students' VSS, especially mental rotation skills.

Based on [70], the concept of merging a sketching strategy and computer integration has been successfully applied in engineering education. This is so because it can link many basic engineering concepts with many concepts from other disciplines. In addition, this approach also provides a practical experience for students. By doing so, students will understand a concept much better and be able to apply it to different situations in the future. According to [72], the use of 3D modeling software as a teaching visual is able to help improve the scores of students' visualization tests. It is also better than the use of two-dimensional CAD modeling or wire frame. This is because 3D block modeling software displays the shape of a 3D object in concrete by displaying shielded lines that represent the side lengths of the object. Furthermore, it can also be obliterated at the user's choice. As such, the confusion with regard to students' vision of the display of a 3D object presented through dynamic 3D block modeling software can be reduced. Reference [73] in their pilot study tested the development of a three-dimensional learning approach (Diedro-3D) to support the teaching process and to overcome the major barriers faced by students when using Geometry textbooks. This is achieved by providing a series of construction steps and by supporting a 3D visualization environment where students can freely change their points of view. The findings show a high level of satisfaction with the learning experience using Diedro-3D.

V. CONCLUSION

In conclusion, learning through SPPD-SUM with step-by-step instructions guides students to independently experiment on 3D objects provided through SketchUp Make dynamic 3D modeling software by rotating, viewing, transforming, and cutting the 3D objects on the screen display. This activity greatly helps students visualize or mentally imagine 3D objects against space (spatial) and translate them to the real world. As previously discussed, these skills are very important in the world of the job market especially those involving designs that require the ability of imagination and precision. In other words, learning through SPPD-SUM can help students improve the ability to mentally rotate, view, transform and cut 3D objects to achieve Geometric thinking of identifying, analyzing, connecting, making series reasoning, and understanding Geometric features. In addition, the 3D objects developed in this activity are close to students' daily lives such as gazebos, playgrounds and swimming pools. This encourages students to train their spatial imagery and to know more closely the series and features of Geometry that can be found from the buildings or constructions around them. In addition, the activities encourage students to remember level thinking, understand concepts, apply, analyze, synthesize, create and evaluate. This is in line with the Revised Bloom's Taxonomy in high-level thinking skills presented by Anderson and Krathwohl in 2001. As a result of this study, we hope that SPPD-SUM will be expanded throughout the country, especially among students in order to help them overcome difficulties in learning Geometry. This is particularly useful for the title of Plan and Incentive, thereby improving students' VSS. In addition, the findings of this study can be used as a guide for teachers to produce Geometry learning materials with the application of VSS via SketchUp Make software for other Geometry topics.

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