Effect of Geometry Instruction Using Van Heile's Theory on Spatial Visualization Ability for Year Five Primary Learners

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Geometry is one of the basic skills which involves the learning of shapes, size, relative position of figures, and the properties of space. Previous studies showed that the learning of geometry requires spatial visualization ability. The purpose of this study was to determine the effect on spatial visualization ability brought about by three different learning strategies based on van Hiele's theory. These strategies were referred to as van Hiele's phases of learning strategy (VH-PL) and van Hiele's theory aided with the use of the Google SketchUp (GSU) software strategy (VH-GSU) and the conventional teaching strategy (NVH-CI). This study adopted the experimental approach involving 96 Malaysian public primary school students who were in Year Five with the two experimental groups VH-PL and VH-GSU while the NVH-CI was the control group. The Spatial Visualization Ability Test was used to measure student ability in spatial visualization. Results showed that there were significant differences in the spatial visualization ability of students who underwent the different teaching strategies. The post hoc test indicated that the use of GSU software in VH-GSU strategy enhances student spatial visualization ability when compared to not using software although both the VH-PL and VH-GSU strategies were based on van Hiele's theory.

Key words: *Geometry, van Hiele's theory, Spatial Visualization Ability, Spatial Visualization Ability Test.*

Introduction

Geometry is a unifying theme for the entire mathematics curriculum and it is involves the learning of geometrical shapes and geometrical relationships. Learning of geometry involves the ability to visualize as most geometrical concepts require visual interpretations (Noraini, 2006; Md. Yunus, et. Al, 2019). In general, spatial visualization refers to the understanding and application of geometrical concepts using visualization-based representations and processes presented in diagrams, computer graphics programs and physical models (Acuña, 2008). The importance of spatial visualization ability in the process of learning geometry is obvious at elementary level as it offers a method to see the hidden, enriches the process of scientific discovery and is a rich source of visualization for arithmetical, algebraic, and statistical concepts (Abu Bakar et. al., 2015; Noraini, 2009; Zimmerman & Cunningham, 1991). In most cases, the lack of spatial visualization ability is found to be the main factor contributing to serious learning difficulties in geometry (Kurtulus & Yolcu, 2013; Pittalis, Mousoulides & Christou, 2010; Rahim & Siddo, 2009).

It is in this case that the spatial visualization capacities of dynamic software programs are shown to be especially useful. Graphs, diagrams, pictures and geometrical shapes or models are tools for visualization of the abstract concepts in geometry. By means of these tools, humans are able to set up a relation between physical or external world and the abstract concepts (Konyalioglu, Ipek & Isik, 2003). Through the use of spatial visualization approach, many geometrical concepts can become concrete and clear for students to understand. Several studies have been conducted on the learning of geometry in Malaysia using van Hiele's model and Geometer's Sketchpad to assist students in learning geometry at secondary level in Malaysia (Chew, 2009; Chew & Lim, 2011; Noraini, 2007; 2009; Abdul Halim, 2013; Abdul Halim & Effandi, 2012; 2013).

This study proposed to look at the effect of using two different instructional strategies on students' spatial visualization ability in the learning of geometry. The two different instructional strategies were van Hiele's phases of learning (VH-PL) strategy and van Hiele's levels of geometry thinking using Google SketchUp (VH-GSU) strategy and these were compared to the conventional teaching strategy (NVH-CI) of teaching and learning geometry. The objective of the study was to establish whether there were significant differences in spatial visualization ability before and after the intervention of the three teaching strategies, specifically between students who underwent the strategies VH-GSU, VH-PL and NVH-CI in learning geometry.

Theoretical Framework

Geometry provides an opportunity for one to improve their spatial visualization ability, an ability which has always been regarded as important in fields such as engineering, architecture and visual arts. As highlighted by Kurtulus and Uygan (2010), geometry is also applied in many daily life activities ranging from rearranging the furniture and objects in our houses, driving around to find a specific address or doing any kind of sport activities. Spatial visualization ability in geometry is described as the ability to imagine the rotation of a represented object, to visualize the configuration, to transform a represented object into other shapes and to manipulate an object in the mind. National Council of Teachers of Mathematics (NCTM) Report (2000) had put forward recommendations for teachers to use visualization, spatial reasoning, and geometric modeling to solve problems.

Chavez, Reys and Jones (2005) posited that developing student spatial visualization skills will greatly benefit their growth in mathematics. Aysegul (2012) reported in his study that relations among spatial ability factors and knowledge factors were positively correlated where spatial visualization and mental rotation abilities were shown to have positive effects on all knowledge factors. Furthermore, spatial perception ability has direct positive effect on declarative and procedural knowledge. Kurtulus and Yolcu (2013) found in their study that more emphasis should be placed on concepts when learning geometry because misconceptions were one of the primary causes of student low level of achievement in spatial visualization.

The traditional way of teaching Geometry emphasises formal definitions and proofs. According to Sunyoung, Yalvac, Capraro and Capraro (2015), teachers sometimes did not change their instructional strategies or acquired misconceptions and in recent years, the teaching of geometry courses has moved to emphasize exploration, problem solving, appreciation and real life applications. As a result of the paradigm shift, dynamic geometry software now plays an important role in the teaching and learning of mathematics. Nolan and Swart (2015) indicated that educational technology may be used to supplement traditional approaches to help the students learn. Noraini's (2007) work reports that the effects of the use of Geometer's Sketchpad on geometry achievement showed significant differences between the control (traditional approach) and experimental (Geometer's Sketchpad) groups. It was also reported that the addition of dynamic geometry software in teaching the topic on geometrical construction had increased student interest in geometry as well as enhanced their understanding through the visualization activities compared to the traditional approach with only chalk and talk.

This observation showed the potential of the dynamic software as an effective tool in learning geometry and therefore encourage classroom teachers and even curriculum developers to use the tools. There are several types of educational software available for the learning of geometry.

However, in this study, Google SketchUp (GSU) had been identified as it had some advantages for classroom use. GSU operates in three dimensions. There are three lines in the diagram: one for height, one for width and one for depth. It can be hard for some people to think that way, but with the help of GSU, the students played with the mouse and managed to view the image on the screen in a three-dimensional space.

The spatial visualization ability in this study was based on the van Hiele's levels of geometry thinking which uses van Hiele's phases of learning in theory. In this theory, the geometry concepts are learnt through a hierarchy of three levels of thinking: (Level 0): recognition/visualization of figures as a whole versus components; (Level 1): analysis of figures by their properties where students start to discover properties/rules of whole groups of figures, and (Level 2): informal deduction where the students logically interrelate previously discovered properties/rules by giving or following informal argument. Spatial visualization ability is strongly related to van Hiele's level 0 (recognition/visualization) as geometry concepts require visual interpretations and geometry problems commonly are presented in a two-dimensional format on paper (Noraini, 2009). She described spatial visualization as the ability to perceive the essential relationships among the elements of a given visual situation and creation of a mental image of a given concept of space. In this study, spatial visualization ability referred to how well students can mentally visualize views and interpret from different-perspectives of two-dimensional pictorial representations (pairing rotated shapes) and three-dimensional structures (find the visible faces of the cubes).

GSU might be useful to help both mathematics educators and learners in learning geometry. This can be done by the incorporation of carefully designed content-related instruction that can help to fix the missing part of predictable sequence of levels in the development of knowledge and also to promote the understanding of geometry concepts during the learning. GSU which works on the windows environment offers facilities to create unlimited two-dimensional and three-dimensional models which are useful features that would facilitate the exercise of visualization-oriented activities, believed to be able to make many geometrical concepts and properties more concrete and clear for students to understand. Thus, GSU would provide a flexible learning tool at a representational level, linking the concrete to the abstract. Mathematical ideas can then be explored from several different perspectives in an efficient manner, resulting in deeper thinking levels of understanding (Kaput & Thompson, 1994). Through repetitive experience of exploring, problem-solving and assimilating, one's ideas can be enhanced. This would certainly be helpful to promote active learning where students are active learners and teachers act as facilitators in their geometry lessons.

Methodology

In this section, the methods adopted in this true experimental study involving two treatment groups and a control group are discussed.

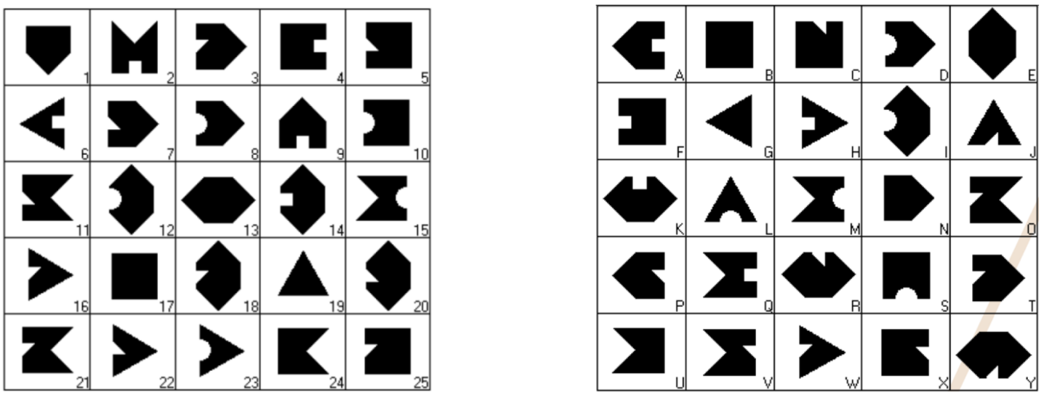
Participants

The study involved 96 elementary school students and 32 of the students were randomly selected into the control group (NVH-CI) and 32 students were placed in each of the two treatment groups, that is, group 1 (VH-PL) and group 2 (VH-GSU). Each group had the same number of students and gender distribution.

Instrument

Student's spatial visualization ability was measured using a specially adapted test where the questions were retrieved from www.psychometric-success.com. This is a free practice test of spatial ability by Paul Newton and Helen Bristoll. The Spatial Visualization Ability test (SVAT) has two separate parts to cater to 2-D and 3-D figures. The 2-D test consists of 25 items which include different orientations of two-dimensional shapes to be matched. On the other hand, the 3-D test consists of five different composite cubes and there are five structured questions to be answered for each picture. The test items were carefully designed to represent specific learning activities pertaining to spatial visualization ability. The total score for the 50 questions obtained by a student would be converted to 100% after the test was marked. The purpose of using Spatial Visualization Ability Test was to examine how well students were able to mentally visualize shapes and interpret from different perspectives of two-dimensional pictorial representations and three-dimensional structures to find the visible faces of the cubes, especially, as it was aligned with the geometry syllabus. Figure 1 below shows a sample test item of the spatial visualization ability.

Figure 1. An Example of Test Items in the Spatial Visualization Ability Test (SVAT)



Group 1 **Group 2**

Validity and reliability of the instrument

The content validity of SVAT was appraised by three experts in this field. They were two mathematics professors from a Malaysian university and a mathematics expert teacher from a primary school. Attention was given to the content in order to determine that the items of instrument showed evidence of content validity. Knowledge and skills required in determining the spatial visualization ability of mathematics was in line with the mathematics syllabus for Malaysian primary school students. A reliability analysis using Kuder-Richardson Formula 20 (KR-20) was conducted through the pilot test to ensure the consistency of the instrument of SVAT. Based on the pilot test, it was determined that the suitable duration of time for this test was one hour.

Table 1 below presents the reliability coefficient of 0.75 for SVAT. In estimating the reliability of instruments, Fraenkel and Wallen (2003) state that the coefficient must at least be 0.70 or higher. Thus, the reliability coefficients obtained from the pilot study indicated that the instruments were reliable for research purposes.

Table 1: Internal Consistency of Instruments

Instruments	KR-20 Reliability coefficient
Spatial Visualization Ability Test (SVAT)	0.75

Results and Discussion

There were 32 (33.33%) students in each of the three groups, that is, treatment group 1 (VH-PL), treatment group 2 (VH-GSU) and control group (NVH-CI) (Table 3). They were 45

(46.9%) boys and 51 (53.1%) girls. These three groups were equivalent in terms of gender as presented in Table 2 below.

Table 2: Profile of Respondents

	Demography			
	Frequency		**Percentage**	
Group	Boys	Girls	Boys	Girls
NVH-CI Control	15	17	15.63%	17.70%
VH-PL Treatment 1	15	17	15.63%	17.70%
VH-GSU Treatment 2	15	17	15.63%	17.70%
Total	45	51	46.89%	53.10%

Table 4 below shows that the three groups had means for pre-test ranging from 49.72 to 54.19. However, the VH-GSU showed the highest increase in scores of the Spatial Visualization Ability post-test ($M = 75.06$, $SD = 8.61$) when compared to the pre-test ($M = 54.19$, $SD = 10.33$) as shown in Table 3 below. The VH-PL group showed an encouraging increase in pre-test score ($M = 49.72$, $SD = 10.64$) to post-test score ($M = 68.63$, $SD = 7.44$). The NVH-CI had also shown slight increase after undergoing the lesson.

Table 3: Mean and Standard Deviation of Spatial Visualization in Pre-Test and Post-Test

	Mean	**N**	**Std. Deviation**
NVH-CI group			
Spatial Visualization Ability Pre Test	52.97	32	9.88
Spatial Visualization Ability Post Test	63.29	32	8.97
VH-PL Group			
Spatial Visualization Ability Pre Test	49.72	32	10.64
Spatial Visualization Ability Post Test	68.63	32	7.44
VH-GSU Group			
Spatial Visualization Ability Pre Test	54.19	32	10.33
Spatial Visualization Ability Post Test	75.06	32	8.61

Paired sample t-test was conducted in exploring the differences in the scores of Pre-test and Post-test. From the analysis, as presented in Table 4 below, there was a statistically significant difference in the overall mean of spatial visualization ability Pre-test (M=52.97, SD=9.88) and Post-test (M=63.29, SD=8.97), [$t(30) = -7.59$, $p = .0001 < .005$]. The effect size of eta squared (η^2) was 0.66 and this showed a large actual effect in the mean scores of Post-test compared to Pre-test in the NVH-CI strategy group (Cohen, 1988). In VH-PL strategy group, there was a statistically significant difference in the overall mean of spatial visualization ability Pre-test (M=49.72, SD=10.64) and Post-test (M=68.63, SD=7.44), [$t(31) = -12.10$, $p = .0001 < .005$]. Eta squared (η^2) was 0.83, It was a large effect (Cohen, 1988) after test performance in the learning of geometry in the VH-PL strategy group using paired sample t-test as shown in Table 4 below.

Table 4: Paired Samples t-Test of Spatial Visualization Ability of Pre-Post Test

Group	Mean	Std. Deviation	Std. Error Mean	t	df	Sig.
NVH-CI	-10.32	7.57	1.36	-7.589	30	.000
VH-PL	-18.91	8.84	1.56	-12.10	31	.000
VH-GSU	-20.88	10.67	1.89	-11.07	31	.000

Table 5 below presents the paired sample t-test which has a statistically significant difference in the overall mean of spatial visualization ability Pre-test (M=54.19, SD=10.33) and Post-test (M=75.06, SD=8.61), [$t(31) = -11.07$, $p = .0001 < .005$]. The Eta squared (η^2) of VH-GSU group was 0.80 which shows large effect as well as VH-PL group after test performance in the learning of geometry (Cohen, 1988). This suggested that there was a significant difference after Post-test. Analysis of Covariance (ANCOVA) was conducted to test for the difference in the overall means of spatial visualization ability after test performance between students who underwent different strategies in learning geometry (VH-GSU, VH-PL and NVH-CI) while controlling their pre-test scores.

Table 5: Tests of Between-Subjects Effects of SVAT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Group	2010.793	2	1005.397	20.014	.000	.305

There was a statistically significant difference in spatial visualization ability as shown in the post-test between the three different groups, [$F(2,91) = 20.01$, $p < .05$], partial eta squared ($\eta2$) was .305 after adjustment for Pre-test of spatial visualization ability as presented in Table 6 below. The eta squared shows 30.5% of large effect among the three different groups (Cohen, 1988). This suggested that there was a significant difference in the overall mean of spatial visualization post-test scores in the three different groups (VH-GSU, VH-PL and NVH-CI) while controlling their pre-test scores.

Table 6: Pairwise Comparisons of Spatial Visualization Ability Post-test

(I) Groups	(J) Groups	Sig.
NVH-CI (M=63.29)	VH-PL (M=68.63)	.001
	VH-GSU (M=75.06)	.000
VH-PL (M=68.63)	NVH-CI (M=63.29)	.001
	VH-GSU (M=75.06)	.043
VH-GSU (M=75.06)	NVH-CI (M=63.29)	.000

	VH-PL (M=68.63)	.043

By using Bonferroni adjustment during Post hoc test, it further analysed which group differed from the other groups in their SVAT scores as presented in Table 7 below. By consulting the significance levels, the VH-GSU group (*M* = 75.06, *SD* = 8.61) statistically significant difference was found when compared to the VH-PL group (*M* = 68.63, *SD* = 7.44) and the NVH-CI group (*M* = 63.29, *SD* = 8.97); while the VH-PL group (*M* = 68.63, *SD* = 7.44) was significantly different when compared to the NVH-CI group (*M* = 63.29, *SD* = 8.97). This suggested that students in the VH-GSU group had better spatial visualization ability when compared to the other two groups after the treatment. The VH-PL group had also performed better than the NVH-CI group.

Table 7: Summary of van Hiele's Levels of Geometric Thinking among Students Before and After Intervention (n=96)

Group	**Level**	**Pre-test**		**Post-test**	
		Number	**Percentage**	**Number**	**Percentage**
NVH-CI	L2	1	3.1	11	34.4
	L1	23	71.9	17	53.1
	L0	6	18.7	3	9.4
	BL0	2	6.3	1	3.1
Mean Scores		60.3		67.7	
VH-PL	L2	1	3.1	17	53.1
	L1	23	71.9	14	43.8
	L0	6	18.7	1	3.1
	BL0	2	6.3	0	0
Mean Scores		57.8		67.6	
VH-GSU	L2	1	3.1	23	71.9
	L1	23	71.9	8	21.8
	L0	6	18.7	1	6.3
	BL0	2	6.3	0	0
Mean Scores		61.0		73.8	

Table 8 below depicts the summary of the van Hiele levels of geometric thinking among the research participants before and after the intervention. Table 7 above shows that during pre-test, all students achieved van Hiele's levels of geometric thinking of L2 and below with six of them in the 'lower than L0' (BL0) level. These six students were considered as those not meeting the van Hiele requirements to learn geometry effectively. This showed that most students only operated at the recognition (L0) (18.7%) and analysis (L1) (71.9%) levels. After the intervention between three different groups using three different strategies, that is, using van Hiele's Phases Learning Module (VH-PL) or van Hiele's Levels of Geometry Thinking using Google SketchUp Module (VH-GSU) and conventional strategy (NVH-CI), the results showed improvement in all three groups. In NVH-CI group, the number of students who progressed to informal deduction level (L2) increased by 10 (31.3%) students. However, in the group of VH-PL and VH-GSU, the number of students increased by 16 (50%) and 22 (68.8%) respectively. This shows that the suggested van Hiele theory successfully helped students to progress to higher levels in learning geometry.

As a conclusion, the SVAT test for the NVH-CI group, VH-PL group and VH-GSU group showed a significant difference in the pre-test and post-test scores of the groups. Of the three instructional strategies, the VH-GSU strategy and the VH-PL strategy had the same effect on the students in their spatial visualization ability. The ANCOVA test showed that the VH-GSU strategy had the best performance in spatial visualization ability followed by the VH-PL strategy and finally the conventional teaching after undergoing the different instructional strategies. The result showed that technology can assist better in spatial visualization ability compared to interacting with paper and pencil learning materials because technology allows exploration of figures inside and outside better than normal traditional learning aids. The use of van Hiele's phases of learning strategy is evidently an added advantage to allow students to progress from one phase to another.

Conclusion

The underlying framework of the design and development of VH-GSU and VH-PL learning strategies was based on the application of van Hiele's theory. One of the strategies, that is, the VH-GSU strategy, capitalized on the advancement of computer technology. In particular, great emphasis had been given to the visualization-based learning activities and hands-on explorations to develop geometric thinking that would actively engage the students in the learning processes and enhance students' geometry understanding. This study had shown that a strong relationship exists between spatial visualization ability and geometry achievement. The inferential statistics of Spatial Visualization Ability Test (SVAT) showed that students from all the three groups had improved in their spatial visualization ability. However, the improvement of students in the VH-GSU group was the best, followed by those in the VH-PL group and finally the NVH-CI group.

This study had provided evidence that the VH-GSU and the VH-PL learning strategies can better assist primary students to improve their spatial visualization ability in the learning of geometry. This finding supported Noraini (2006, 2009) who claimed visualization was a necessary tool in geometry concept formation. It would therefore be helpful to students if their geometry lessons could be carried out with hands-on activities so that students can "touch-see-and-do", thereby interacting with the objects of their learning. In this study, the VH-GSU strategy was found to be a better choice as students gain a 360 degree view of the object and this assisted them in getting a better conceptual understanding. Conversely, the VH-PL module was more about interacting with learning materials. The learning materials used in the activities also helped students to improve their geometrical understanding.

Visualization in geometry learning was addressed in van Hiele's model. Level 0 (Visualization) of van Hiele's levels of geometry thinking requires students to visualize and explore the properties of geometric objects. By kinesthetically handling and visualizing geometric solids, students obtain information directly through touch and sight. Hence, students can increase their conceptual understanding on the nature of geometry objects. In terms of spatial visualization ability in geometry achievement, NCTM (2000) stated that the curriculum of Mathematics must be designed to equip students with the mathematical methods that support the full range of problem solving skills, including the use of imagery, visualization and spatial concepts (NCTM, 2000). In Malaysia, Noraini (2006) stated that one of the problems in geometry learning is that the traditional approaches of geometry instruction do not seem to help students to achieve the intended learning outcomes as outlined in the curriculum documents. Since spatial visualization ability can assist in geometry achievement (Jiang and R. Smith, 2017; Aysegul, 2012; Noraini, 2005; Olkun, 2005; Rahim, 2009), there appears to be an urgent need to change the traditional mode of geometry instruction to one that is more rewarding for the students and teachers in Malaysia.

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