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The Effect of *Geometers' Sketchpad* on the Performance in Geometry of Malaysian Students' Achievement and van Hiele Geometric Thinking

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ABSTRACT

This study was designed to investigate the effect of using Geometers' Sketchpad on performance in geometry achievement and the level of van Hiele geometric thought among Form Two students in one of the secondary schools in Kuala Lumpur. The van Hiele Geometry Test was administered to determine their level of geometric thought according to van Hiele theory. This Quasi-experimental research was carried out in one of the secondary schools in Kuala Lumpur. A total of 65 Form Two students from the school were chosen for this research. The treatment group (N=32) underwent the lessons using the Geometers' Sketchpad for ten weeks. At the same time the control group (N=33) was taught by the traditional approach. The questionnaire and checklist were administered to explore the students' response to wards to the use of Geometer's Sketchpad on learning of geometry. A descriptive analysis showed that most of the students agreed that the Geometer's Sketchpad is a useful tool for learning geometry. The findings of this study about the effects of Geometer's Sketchpad and van Hiele model will be useful to mathematics teachers, educators and those who are involved in the teaching of mathematics, particularly geometry in the planning of teaching activities for the classroom.

Keywords: Geometers' sketchpad, geometry achievement, van Hiele theory, level of geometric thinking, geometry, learning van Hiele geometric test

INTRODUCTION

Learning of geometry is formally introduced in the Malaysian primary mathematics curriculum. The emphasis in geometry increases as students progress to secondary education, where about forty percent of the sixty topics in the five-year secondary mathematics curriculum comprises geometry content (Malaysian Ministry of Education, 1998). It is paramount that students at the beginning level of secondary education are provided with logical reasoning skills to build on subsequently more rigorous experiences of formal geometry. The Curriculum and Evaluation Standards for School Mathematics (NCTM, 2000), and other important literature in the area of mathematics education calls for emphasis in geometry at all levels. Geometry is a unifying theme to the entire mathematics curriculum and as such is a rich source of visualization for arithmetical, algebraic, and statistical concepts. For example, geometric regions and shapes are useful for development work with the meaning of fractional numbers, equivalent fractions, ordering of fractions, and computing with fractions (Sanders, 1998, p. 20).

Topics of triangles and quadrilaterals are covered from primary to secondary schools. Thus, the students are able to identify triangles and quadrilateral since Year One. However, according to Noraini Idris (1999), from her clinical interviews conducted on 13 and

14-year-ole students from a public school in Kuala Lumpur, Malaysia, it was found that the words "square" and "rectangle" were not part of their normal vocabulary.

Geometric concepts are often neglected in elementary and middle level schools in favour of teaching computational skills (Huetinck & Munshin, 2004; Noraini Idris, 2006). Various reasons related to the mathematical system itself, curricular materials, instructional practices, and cognitive development have been proposed to explain students' the difficulties with geometry.

As students are introduced to increasingly abstract concepts and exposed to relational operators such as equal, congruent, and similar, their mental models of the relationships among concepts require continual restructuring (Battista *et al.*; van de Walle, 2001; Olive, 2000). From the perspective of the van Hiele model of the development of geometric thought, the student moves from observing and identifying the figure to a recognition of it properties, to understanding the interrelationships of the properties of the figures and the axiomatic system within which they are placed (Usiskin, 2003).

Geometers' Sketchpad provides a flexibly structured mathematics laboratory that supports the investigation and exploration of concepts at a representational level, linking the concrete to the abstract. Mathematical ideas can be explored from several different perspectives in an efficient manner, resulting in deeper conceptual understanding (Kaput & Thompson, 1994). Through repetitive experiences of exploring, problem skills and one's ability to assimilate ideas are enhanced (Cooper, 1991). Students should be viewed as active learners and teachers as facilitators of learning.

In many Malaysian schools, the teaching and learning of mathematics has been reported to be too teacher centred and that students are not given enough opportunities to develop their own thinking (Ministry of Education, 2001). This situation invariably results in students becoming passive receivers of information, which in many cases do not results in conceptual understanding. Many students are not able to comprehend what their mathematics teachers teach especially on the topic of geometry because mathematics content is taught with the intention of finishing the syllabus and preparing for examinations. Little regard is given to how well the students understand geometrical concepts. On the topic of geometry, students encounter difficulties in applying what they have learnt as they were not given enough time to understand the geometry concepts. Instead they were just memorizing the concepts. Thus, the researcher investigated geometrical thinking of Form Two students in a national Malaysian school.

STATEMENT OF THE PROBLEM

Learning geometry may not be an easy and a large number of the studenes fail to develop an adequate understanding of geometry concepts, geometry reasoning, and geometry problem solving skills (Battista, 1999; Mitchelmore, 2002). The lack of understanding in learning geometry often causes discouragement among the students, which invariably will leads to poor performance in geometry. A number of factors have been put forward to explain why learning geometry is difficult - geometry language, visualization abilities, and ineffective instruction.

Poor reasoning skills are also another area of concern among secondary school students. Many are unable to extract necessary information from given data and many more are unable to interpret answers and make conclusions. Traditional approaches in learning geometry emphasize more on how much the students can remember and less on how well the students can think and reason. Thus learning becomes forced and seldom brings satisfaction to the students. This study was designed to explore the effects of Geometers' Sketchpad on van Hiele geometric thought.

CONCEPTUAL FRAMEWORK

The van Hiele Model of Learning in Geometry

The conceptual framework of the van Hiele Model of learning geometry was built on a model consisting of five levels of thought development in geometry, presented by the Dutch educators van Hiele and his late wife, Dina van Hiele-Geldof in 1957. This model has motivated considerable research and resultant change in the geometry curriculum.

The van Hieles were greatly concerned about the difficulties their students encountered with secondary school geometry. They believed that secondary school geometry involves thinking at a relatively high "level" and students have not had sufficient experiences in thinking at the prerequisite lower "level."

The van Hiele model has three main components: insight, phases of learning, and thought levels (Hoffer, 1983; Usiskin, 2003). Many of the ideas for the insight and structure component were "borrowed from Gestalt theory" (van Hiele, 1986, p. 5). "Insight exists when a person acts in a new situation adequately and with intention. The Gestalt psychologist and I say the same thing with different words" (van Hiele, p. 24). In most Malaysian classrooms in Malaysian or in other countries, students learn a language to accompany the structure, although it is possible for students to construct visual structures in their minds and be able to continue the structure without using language (Collier, 1998; Noraini Idris, 1999).

The second component of the van Hiele model, the phases of learning, describes the phases through which students progress through in order to attain the next higher levels of thinking. Basically these phases constitute an outline for organizing instruction. Van Hiele (1986) identifies five phases in this learning process and gives an example of the stages in the study of the rhombus:

1. In the first phase, instructions should begin with an inquiry phase in which materials lead children to explore and discover certain structures. That is, through working with materials presented to them, students become acquainted with the structure of the material, such as, examining examples and non-examples of geometric concepts. For example, a certain figure is demonstrated, it is called "rhombus." The pupils are shown other geometrical figures and are asked if they also are rhombuses.

2. In the second phase, guided by tasks (given by teacher or done by students) with different relations of the network that has to be formed. Students actively engage in exploring objects (for example, folding, measuring) so as to encounter the principal connections of the network of relations that is to be formed. For example, students are asked to fold the rhombus on its axes of symmetry and observe what happens to the diagonals and the angles.
3. In the third phase, explicitation, pupils become conscious of the relations, they try to express in words and learn the technical language accompanying the subject matter. For example, the pupils exchange their ideas about the properties of a rhombus.
4. In the fourth phase, free orientation, pupils learn by general tasks to find their own way in the network of relations. For example, some vertices and sides of a rhombus are given by position. The whole rhombus has to be constructed.
5. In the fifth phase, integration, pupils build an overview of all they have learned of the subject, of the newly formed network of relations now at their disposal. For example, the properties of a rhombus are summed up and memorized (pp. 53-54).

The transition form one level to the next is a learning "process that has to done by the pupils themselves" (van Hiele, 1986, p. 62). Teachers can give guidance to the students during this complicated exercise: "Transition from one level to the following is not a natural process; it takes place under the influence of a teaching-learning program" (p. 50). The teachers' choice of lessons and activities is critical in the transition from one level to the next. In this manner, teachers help students find ways to ascend to the next higher level. During the transition, van Hiele considers discussion to be the most important part of the teaching-learning process and without learning a new language, the transition is impossible.

The third component of the van Hiele model grew out of the concern the van Hieles' felt concerns when their geometry students repeatedly encountered difficulties with parts of the subject matter even after being given various explanations. Their joint interest in wanting to improve teaching outcomes led to the development of a theoretical model involving five levels of geometric thinking.

According to the van Hieles, the learner, assisted by appropriate instructional experiences, passes through the following five levels, where the learner cannot achieve one succeeding level of thinking without having passed through the previous levels. It is clear that, throughout those phases of learning, the teacher has various roles: planning tasks, directing students' attention to geometric qualities of figures, introducing terminology and engaging students in discussions using these terms and encouraging explanations.

Hoffer (1981) describes the van Hiele levels of learning in geometry in the following manner:

Level 1: Recognition. The students identifies, names, compares and operates on geometric figures (e.g., triangles, angles, or intersecting) according to their appearance.

Level 2: Analysis. The student analyzes figures in terms of their components and relationship among components and discovers properties/rules of a class of shapes empirically (e.g. by folding, measuring, using grid or diagram).

Level 3: Ordering. The student logically inter-relates previously discovered properties/rules by giving or following informal arguments.

Level 4: Deduction. The student proves theorems deductively and established interrelationships among networks of theorems.

Level 5: Rigor. The students establishes theorems in different postulational systems and analyzes/compares these systems (pp. 35)

The van Hieles made certain observations about the general nature of these levels of thinking and their relationship to teaching van Hiele (1959) notes:

> "At each level there appears in an extrinsic way that which was intrinsic at the preceding level. At level 1, figures were in fact determined by their properties, but someone thinking at level I is not aware of these properties" (p. 202).

Since his initial work, van Hiele has focused his attention and in-depth descriptions to Level 1 through 4, for it is at the lower levels that most geometry students function. It is more likely that a thorough understanding of the lower levels will lead to improving the teaching and learning of geometry. The higher levels are easily over-valued and have only of theoretical value.

The main characteristics of the levels are:

1. They levels have a hierarchic arrangement through which the person moves sequentially
2. Moving from one level to the next is more a result of a learning process rather than a result of age or maturation
3. The learning process which leads to a higher level is distinguished by various phases of learning.
4. Each level has a unique language, set of symbols, and network of relations joining these symbols.
5. What appears in an explicit manner at one level is intrinsic at the preceding level.
6. A person reasoning at the higher level cannot be understood by another person at a lower level.
7. Material taught above a person's level may be reduced to a lower level by that person.

The levels of thinking grew out of van Hiele's interest in improving instruction in geometry, however the same "levels" approach can be used in the teaching and learning of other topics as well (van Hiele, 1986).

van Hiele (1959) states that the levels are "characterized by differences in objects of thought" (p. 14). For example, at level 1, the objects of thought are geometric figures. At level 2, the student operates on certain objects, namely, classes of figures, which are products of level 1 activities and discovers properties for these classes. At level 3, these properties become the objects that the student acts upon, yielding logical orderings of these properties.

At level 4, the ordering relations become the objects on which the student operates and at level 5, the objects of thought are the foundation of these ordering relations.

van Hiele and van Hiele-Geldof (1959) notes that learning is a discontinuous process and that there are jumps in the learning curve which reveal the presence of "levels". They observed that at certain points of instruction: The learning process has stopped. Later on it will continue itself. In the meantime, the student seems to have "matured". The teacher does not succeed in explaining the subject. He seems to speak a language which cannot be understood by pupils who have not yet reached the new level. They might accept the explainations of the teacher, but the subject taught will not sink into their minds. The pupils himself feels helpless, perhaps he has no view of his own activity until he has reached the new level (1958, p. 75).

The van Hiele model of geometric thought proposes a means for identifying a student's level of intellectual maturity in geometry and suggests ways to help the student progress from one level to the next. Progress from one level to the next, asserts van Hiele (1959), is more dependent upon instruction than on age or biological maturation, and type of instructional experiences can affect progress.

Research supports the accuracy of the model for assessing student understandings in geometry (Bogg *et al.*, 1999; Battista & Burrow, 1997; Fuys, Geddes, & Tischler, 1988; Hoffer, 1981). Wirszup (1976) reported on the success of the Soviets in implementing a curriculum based on the van Hiele levels of learning. Mayberry (183) found that students can be on different levels for different concepts. Problems occur when teachers do not match the level of instruction to the students' van Hiele levels (van Hiele, 1986).

PROCEDURE

Sample

This study adopted a quasi-experimental research design. A total of 65 Form Two students were chosen for this research. 32 students of the treatment group underwent the lessons using the Geometers' Sketchpad for ten weeks. At the same time the control group was taught by traditional approach.

Instrumentation

The students' van Hiele level of geometric thinking were assessed by van Hiele Geometry Test (VHGT). The test-retest reliability of van Hiele levels are 0.71. Pre- and post-tests of geometry test and VHGT were administered to both the experimental and control groups to compare the achievement geometry and van Hiele levels of Geometric Thinking. The questionnaire was administered to investigate the students' response towards the use of Geometers' Sketchpad on learning of geometry.

Instructional Materials

Different instructional materials were used for the experimental and control groups. Experimental groups used instructional activities based on Geometers' Sketchpad as shown in *Figs*. *1* and *2* below.

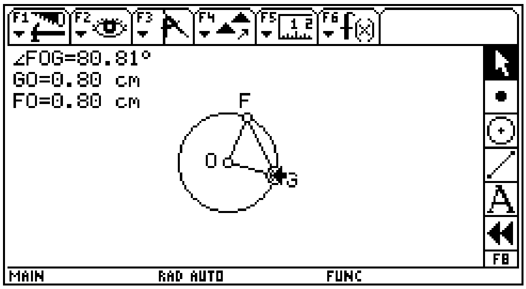

Fig. 1: Drawing of triangle

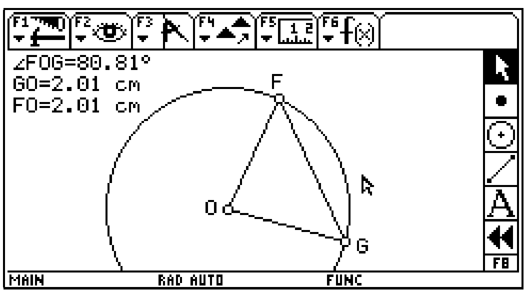

Fig. 2: Enlargement of triangle

The activities allowed the students to explore, investigate, discover, reflect, and visualize the geometrical concepts based on Geometer's Sketchpad to help the students in upgrading their mathematical understanding and attain higher mathematical achievement.

The students were first given an introductory lesson on the basic use of the Geometers' Sketchpad. The prepared activities were used in the following lessons and the teachers would teach more Geometers' Sketchpad skills as the lessons progressed. In the control groups, the topics were taught with the use of mathematics textbook and without the use of Geometers' sketchpad.

Data Analysis

Descriptive statistics of frequencies was computed using the S Plus 6 statistical package to compare the differences of the students van Hiele Geometric Thinking of both the control and experimental groups.

RESULTS

Effects of Geometer's Sketchpad on Geometry Achievement

The result as shown in Table 2 show that in the pre-achievement test, there is no significant differences between experimental and control groups at $p < 0.05$. In the post-test, the control group exhibited a mean of 13.08 whilst the experimental group showed a mean of 19.65. The computed t-value between the post-test of the control and the experimental groups showed a value of 2.78 with $p = 0.02$. The results showed that there is a significant differences between the control and experimental groups.

Effects of Geometer's Sketchpad-based Instructions on van Hiele Level

The subjects were sorted by group and by change in van Hiele level from pre- to post-test. After post-testing, all subjects either remained at the same level or were assigned to a level one or two above their pretest level. Table 1 shows changes in student level from pretest to post-test for the experimental and control groups.

TABLE 1
Mean, standard deviation and t-values for experimental and control groups

Test	Groups	Mean	Std Dev.	t-values	p-sig
Pretest	Control	6.71	1.19	0.788	0.43
	Experimental	6.69	1.18		
Post-test	Control	13. 08	6.78	2.78	0.02
	Experimental	19.65	5.97		

P< .05

As shown in Table 2, the ordered pair (3, 14) under column 0 indicates that there were three students in the experimental group and fourteen students in the control group who remained the same from pre- and posttest. The ordered pair (5, 1) under level 2 indicates that five students in the experimental group and one in the control group moved from level 1 to level 2.

TABLE 2
Comparison of students' pre- and posttest van Hiele levels (experimental, control)

Pre	Post-test				
	0	1	2	3	4
0	(3, 14)	(8, 6)			
1		(4, 6)	(5, 1)	(1, 0)	
2			(4, 5)	(2, 0)	
3				(3, 1)	
4					(2, 0)

To answer the question whether subjects in the experimental group using Geometers' Sketchpad achieved significantly greater change in van Hiele levels compared to subjects in the control group who did not use Geometers' Sketchpad, a Kruskal-Wallis test was performed on the data. The result of the test with $\chi^2 = 18.72$, df = 1, indicates a significant differences ($p < 0.01$) between treatment and control groups on subjects' change in rank on van Hiele levels from pre-test to post-test.

Perceptions of Students towards the Use of Geometers' Sketchpad (GSP)

Thirty three form two students completed a form with the questions as shown in Table 2. The scaled score is calculated based on 5 - strongly agree, 4 - agree, 3 - not sure, 2 - disagree, and 1 - strongly disagree.

TABLE 3
Students' survey results on the usage of geometers' sketchpad

Item	...5	...4	...3	...2	...1	Min
1. Geometers' Sketchpad help me in understanding the topics	...12	...11	5	...5	...0	3.91
2. GSP help to visualize	...10	...13	...7	...3	...0	3.89
3. I am able to interact with my teacher & friends	...12	...13	...6	...1	...1	3.92
4. I feel confident about trying a new problem.	...11	...14	...6	...2	...0	4.01
5. Geometers' Sketchpad make me feel comfortable learning geometry	...12	...13	...5	...2	...1	3.94

As shown in Table 3, most of the students showed positive reactions towards the use of Geometers' Sketchpad. Students felt confident about trying a new problem on the Geometers' Sketchpad with a min 4.01. Students felt that Geometers' Sketchpad made them comfortable learning mathematics, min 3.94.

DISCUSSION AND CONCLUSIONS

From the results obtained, a number of implications can be forwarded in the interest of improving geometry teaching in the classroom. Firstly, the significant differences in geometry achievement of the experimental groups as compared to the control groups indicate that the geometer's sketchpad shows promising implications for the potential of using the Geometers' Sketchpad in teaching geometry the secondary school level. The resulting of this study is consistent with the Sanders (1998) study which reported that the addition of dynamic geometry software in geometric construction has increased her students' interest in geometry as well as enhancing their understanding. This observation can therefore encourage classroom teachers and even curriculum developers on the potential of the Geometer's Sketchpad as an effective tool in learning geometry.

van Hiele-based instructional materials and the use of Geometers' Sketchpad played a special role in helping students to progress within a level or to a higher level (Elchuck, 1992; Engebretsen, 1997; Glass *et al*, 2001; Schattschneider & King, 2001, Noraini Idris, 2006). Tasks that involved a variety of environments in which the concepts were embodied, such as drawing, identifying and exploration, revealed modes of reasoning about specific concepts that the researcher could identify with confidence. According to the van Hiele model, each learning period builds on and extends the thinking of the proceding level. This is significant for teachers in selecting and sequencing instructional activities in accordance with the model.

Effective learning occurs as students actively experience the objects of study in appropriate contexts of geometric thinking and as they engage in discussion and reflection using the language of the learning period. Awareness and knowledge of students' van Hiele levels can be a useful asset and tool to the geometry teacher in the classroom. The significant improvement of geometry achievement/performance on account of the specially prepared van Hiele-based instructional and Geometers' Sketchpad used in this study also suggest that there is a need to provide more interactive and hands-on learning activities for geometry learning at the lower secondary school level.

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