A CASE STUDY ON VISUAL SPATIAL SKILLS AND LEVEL OF GEOMETRIC THINKING IN LEARNING 3D GEOMETRY AMong HIGH ACHIEVERS

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Since geometry mainly comprises of three-dimensional (3 D), visual spatial skills and level of geometric thinking are essential in the teaching and learning of Geometry. In addition, it is also important in other fields, such as engineering, design, graphics, film, science, chemistry, business and arts. Visual spatial skills comprise the ability to imagine, illustrate and describe visual process happens in the mind. Visual spatial skills and levels of geometric thinking have been claimed to cause difficulties in the learning of geometry. Therefore, this case study was conducted to assess students’ visual spatial skills and level of geometric thinking among high achievers. A total of 133 respondents participated in this study, which consisted of 62 male and 71 female respondents. The study used a testing tool which can measure visual spatial skills performance. The testing tool measured five visual spatial abilities, such as combining 2-D, rotation, view, manipulation, and cut. Visual spatial skills were tested using a standard Spatial Visualization Mental Test: Purdue Spatial Visualization Tests of Rotation of Development (PSVT: D), Purdue Spatial Visualization Tests of Rotation (PSVT: R), Purdue Spatial Visualization Tests of View (PSVT: V), Transformation 3D to 2D test (T3D2DT), and Mental Cutting Test (MCT), while the van Hiele Geometric Thinking Test (vHGT) was employed to find out the level of students’ geometric thinking. Data in the forms of frequency, mean, and percentage were presented using graphs and tables. The results indicated that the students’ levels of mental ability in rotation, view, and cut were low. On top of that, the students’ level of geometrical thinking was found at a level of concern as majority of the students were at lowest level (Level L1). Findings retrieved from the study are described in detail in this paper.

Introduction

Learning geometry has started from pre-school up to high school and continued at higher levels in the chosen field of higher educations. Mastery of geometry concepts will stimulate students’ interest to learn mathematics wider and challenging (Jones, 2002). Students are taught the concept of geometric shapes and space as early as during preschool (Curriculum Development Division, 2010). At this stage, students are introduced to a variety of 2 Dimensional and 3 Dimensional geometric shapes, including the relationships between them. Basic introduction to shapes, sizes, and space, as well as identification of series of geometry and geometric properties are emphasized in primary schools, while the use and relationship between series and properties of geometry are directly and indirectly emphasized in the syllabus at secondary level. This is explained by the ratio of the syllabus contents from Form
One until Form Five, whereby 42\% of the 60 topics are geometry topics (BPK, 2000).

On top of that, Jonassen (2003), Jones and Mooney (2004), and Presmeg (2006) asserted that learning geometry should be based on actual situations. Besides, Kyttälä and Lehto (2008) and Noraini (2006) also emphasized the involvement of visual spatial in developing mental representation. However, the teaching of geometry in Malaysia has been reported as being too dependent on the content given by the teachers (Noor Izana, 2012). Meanwhile, Salleh, Bilal and Tan (2012) disclosed a disappointment when they revealed that teachers relied solely on the contents of textbooks, although progress in geometrical thinking depends on students’ experiences with the concept of geometry and their ability to achieve visual spatial skills and not solely on maturity. Furthermore, Abdul Halim and Effandi (2013) explained that the current classroom teaching and learning activities have failed to make students associate what they have learnt with their real-life situations. In fact, approaches and teaching methods are still confined to traditional teacher-centered approach. In addition, the geometry learning activities are uncreative and uninteresting since teachers only use blackboard to explain theorems, definitions, and concepts (Noraini, 2000; Abdul Halim & Effandi, 2013). This phenomenon has also been reported by Mullis et al., (2012) in TIMSS 2011, which claimed that 83\% of Malaysian teachers were dependent on textbooks in teaching and learning mathematics, 55\% applied memorization, and 64\% through explanation. This dependency offers students limited opportunity to improve their visual spatial skills and to develop their geometrical thinking. This finding contradicts the educational goals of 3D geometry, as the teaching and learning of geometry should expose students to the awareness of space (spatial), geometric thinking, the ability to describe visualization, to build knowledge and understanding, as well as the ability to use the features and geometry theorem (Jones, 2002; NCTM, 1979).

In addition, Noraini (2006) and Abdul Halim and Effandi (2013) disagreed with the practice of teachers who help students to solve given problems by showing methods and algorithms, as well as intensive training, hoping that the students will be familiar with the questions. However, unfortunately students will be just memorizing them without really understanding the concepts of geometry. Apart from that, Noraini (2009) verified that the emphasis on 3D geometry concepts should require students to draw a picture of an object and to identify the distinguishing characteristics with existing experience. Consequently, these skills require visual interpretation as the geometry problems are presented in 2-D on the question paper. Therefore, failing to analyze 3D geometric information, which is a drawing in isometric view on paper, the student will have difficulty in understanding the questions which involve solid geometry (Norani, 2006). Previous studies have indicated that among the difficulties faced by students in learning 3D geometry
Problem Background

Many studies which were conducted on the difficulties of learning geometry were focused on determining the level of progressive thinking and wondering profile geometry in numerous geometrical problems. Lawrie, Pegg and Gutierrez (2000) clarified that generally van Hiele’s model has been used in the studies. The Model of Level Thinking van Hiele Geometry outlines the hierarchical level at which students’ proceed to higher level as their ideas of geometry progress. This model finds loopholes of reliance in traditional teaching approach and provides a way to improve the focus and the emphasis on students’ geometrical thinking in order to obtain the appropriate level in mastering high school geometry successfully. Furthermore, Noraini (2009) and Abdul Halim and Effandi (2013) recognized that students’ have weakness in reasoning skills and therefore it creates difficulties for them. Thus, many students are unable to obtain the required information from the data given, possess difficulties to interpret the answers and to draw conclusions.

In addition, Konyaliog and Aksu (2012) reported that the difficulties in understanding the concept of geometry and solving problems in geometry among students were due to their weakness in visual spatial skills. This idea is supported by Chiang (2012), who believed that the difficulties in visual spatial skills are the reasons for students to have problems in learning geometry and become a significant cause of low achievement in mathematics. Meanwhile, Bender (2008) stated that students who experience problems or difficulty in analyzing, interpreting, and understanding what they see and hear will fail to process a given problem. On top of that, Sorby (2006), Alias, Black and Gray (2002), and McGee (1979) defined visual spatial skills as a fraction of cognitive abilities involving mental manipulation, rotation, tightening, or pictorial displays in a block. Hence, visual spatial skills are essentials in learning geometry. Besides, traditional teaching and learning approach tend to force students to memorize and less emphasis is given on how students should think, draw a picture (visual), and subsequently decide the progress to be made. This mode of learning will often fail to bring satisfaction to students (Noraini, 2007).

Furthermore, learning geometry approach based on traditional method is irrelevant nowadays since it contributes towards the failure to foster students’ higher-order thinking skills. Besides, Abdul Halim and Effandi (2013) and Battista (2001) believed that the traditional approach in learning geometry which emphasizes on...
memorization do not promote students to think and reason. Therefore, Battista (2002) asserted that the objective of traditional learning has failed to give satisfaction and does not offer meaningful learning among students. This failure has been clarified by Mullis et al. (2012), who reported that only 33% of Malaysian students answered correctly the geometry questions in TIMSS 2011 international examination. As for the cognitive domain in geometry, Malaysian students’ performance were below the international average score, whereby only 45% of students mastered the cognitive domain knowledge, 38% in cognitive domain of application, and only 33% in cognitive domain of reasoning. Therefore, further studies need to be conducted to identify appropriate geometry learning approaches to address this issue based on the two objectives of learning geometry outlined by National Council of Teachers of Mathematics (1979), namely to develop geometric thinking and to improve visual spatial skills, which refers to the perceptions of space and the real world.

Although most of the studies in the field of geometry in Malaysia were conducted by Norani (2009), Abdul Halim and Effandi (2013), Tan (2011), Chiang (2012), and Zaid (2014) recognized the importance of visualization skills to be applied in teaching approaches, they did not conduct in depth investigation on how to improve the effect of teaching approaches towards students’ visual spatial skills. Besides, previous geometry researchers were more focused on using visual approach, namely a dynamic software technology in order to enhance students’ geometrical thinking skills. However they failed to assess the effectiveness of the software towards students’ visual spatial skills. In fact, only a few studies in Malaysia were carried out to demonstrate teaching and learning approaches based on visualization using dynamic enhanced visual spatial skills in improving the understanding of geometry 3D. The studies were conducted by Abdul Rashid (2008), Azlina and Lok (2010), and Suhaila (2008). Consequently, the studies did not focus on the progress of students’ geometry thinking level.

Based on the information and evidence mentioned earlier, there are indications that the learning difficulties experienced by Malaysian students in learning geometry are associated with visual spatial skills specifically related to three-dimensional objects. There are also indications that the learning difficulties experienced by Malaysian students in learning geometry are associated with weakness and inconsistency in van Hiele levels of geometric thought. The question is, whether learning difficulties in geometry also occurs among high achievers in Malaysia? Moreover, in order to overcome learning difficulties in geometry, the reliability and validity of these indicators have been studied rigorously and systematically via follow-up action. Therefore, the researchers conducted a case study to assess if the problems and difficulties in geometry for visual spatial skills and geometric thinking also occurred among high achievers. This case study was conducted at one boarding school in Johor. These students are excellent students in UPSR and PT3. They come from all the states in Malaysia. The high-achieving students are
enrolled in boarding schools across Malaysia and their performances are monitored and guided. This effort is to produce first-class workers, who excel academically and competent in various skills. However Van de Wall et al. (2010) pointed out that high achievers’ students are still not considered successful, if they fail to capitalize their visual spatial skills and possess low level geometric thinking. Moreover, Malaysian Ministry of Education in its initial report of PPPM (2012) disclosed its apprehensiveness over increasing students’ achievements in UPSR, PMR/PT3 every year, however the results for the assessment of TIMSS is decreasing.

**Purpose of Study**

This study assessed if the learning difficulties in geometry which was related to students’ visual spatial skills and students’ geometrical thinking also occurred among high achievers. The study focused on students’ mental ability to combine two-dimensional plane, rotate, view, manipulate, cut-off, as well as to look into the level of geometrical thinking. This case study intended to answer the following research questions:

i) What is the level of visual spatial skills among high achievers?

ii) What is the level of geometric thinking among high achievers?

**Research Methodology**

A total of 133 form four students comprising of 62 boys and 71 girls from a secondary school for high achievers in Johor was involved in this case study. The instrument consisted of five domains of visual spatial ability were used in this research had already existed and widely used by researchers on visual cognition such as Onyancha and Kinsey (2007) and Prieto and Velasco (2002). The instruments were based on standard criteria for spatial ability, as suggested by Sorby (2006) and manipulation test (namely T3D2DT) developed by Safarin (2009). Hence, in order to measure a student’s ability in merging 2-D mentally, Purdue Spatial Visualization Test For Development (PSVT: D) was employed. Meanwhile, Purdue Spatial Visualization for Rotation Test (PSVT: R) was used to measure the ability to rotate mentally, whereas to measure a student’s ability to describe an object from the viewpoint of mental assigned, the Test of PSVT: V was used. Besides, Mental Transformation test for 3D to 2D (T3D2D) was used to measure the ability to manipulate mentally, while Mental Cutting Test (MCT) measured mental cut abilities. In addition, van Hiele Geometric Thinking (vHGT) Test was applied to measure the level of students’ geometric thinking. The vGHT test has been used widely by researcher such as Usiskin (1982), Abdul Halim (2013) and Vojkuvkova and Haviger (2013).

Students’ scores for each spatial ability tests were based on the number of correct answers. However, the scores were transformed into percentages to facilitate data analysis. After that, the Level of Schedule Spatial Ability was referred to
define the level of students’ visual spatial skills based on the percentages adapted from Sorby (2006), as depicted in Table 1. As for the vGHT test, Usiskin (1982) declared that when respondents answered correctly at least 3 of 5 items at any level in vHGT, the respondents were considered to have mastered it. Furthermore, to define the level of students’ geometrical thinking, the scores obtained by the students were calculated based on the weighted scores established by Usiskin (1982), as portrayed in Table 2.

**TABLE 1: INTERPRETATION OF SCORES FOR THE LEVEL OF VISUAL SPATIAL SKILLS**

<table>
<thead>
<tr>
<th>Score (%)</th>
<th>Category</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>61-100</td>
<td>Above average score</td>
<td>Strong</td>
</tr>
<tr>
<td>41-60</td>
<td>Slightly below the average score</td>
<td>Moderate</td>
</tr>
<tr>
<td>0-40</td>
<td>Below average score</td>
<td>Weak</td>
</tr>
</tbody>
</table>


**TABLE 2: WEIGHTED VAN HIELE GEOMETRIC THINKING TEST SCORES**

<table>
<thead>
<tr>
<th>Item no.</th>
<th>Level of van Hiele</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Geometry Thinking Test</td>
<td></td>
</tr>
<tr>
<td>1,2,3,4,5</td>
<td>L1</td>
<td>1</td>
</tr>
<tr>
<td>6,7,8,9,10</td>
<td>L2</td>
<td>2</td>
</tr>
<tr>
<td>11,12,13,14,15</td>
<td>L3</td>
<td>4</td>
</tr>
<tr>
<td>16,17,18,19,20</td>
<td>L4</td>
<td>8</td>
</tr>
<tr>
<td>21,22,23,24,25</td>
<td>L5</td>
<td>16</td>
</tr>
</tbody>
</table>

*Source:* Usiskin (1982)

For example:
Students who obtained the scores at levels 1, 3, and 4, their score was 13 (1 + 4 + 8).

Moreover, in order to facilitate the development of students’ geometrical thinking in the categories above, Usiskin (1982) described 32 scores, starting with score 0 to 31. Then, Abdul Halim (2011) explained that in order to determine students’ level of geometric thinking, the table of van Hiele’s level of force should be referred to, as displayed in Table 3.

**TABLE 3: TABLE OF VAN HIELE’S LEVEL OF FORCE**

<table>
<thead>
<tr>
<th>van Hiele Level of Force</th>
<th>Score total weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>*L1</td>
<td>0,2,4,8,16,18,20 or 24</td>
</tr>
<tr>
<td>L1</td>
<td>1,5,9,17,21 or 25</td>
</tr>
<tr>
<td>L2</td>
<td>3,11,19 or 27</td>
</tr>
<tr>
<td>L3</td>
<td>6,7,22 or 23</td>
</tr>
<tr>
<td>L4</td>
<td>13,14,15,29,30 or 31</td>
</tr>
<tr>
<td>Not in any weighted</td>
<td>10,12,26 or 28</td>
</tr>
</tbody>
</table>

Level *L1* is categorized for phase under L1
*Source:* Usiskin (1982)
Findings

The findings in this study showed that the lowest skill concerning mental ability was mentally cut by 91% in the weak category and afterwards, the ability to view mentally with 47% in the weak category, as reflected in Table 4. Based on Figure 1 above, the mean score of visual spatial skills for the combination of 2D and Manipulation was at a moderate level. Meanwhile, it is clear that mental cutting test was the lowest mean attained among the higher achievers.

TABLE 4: DISTRIBUTION OF VISUAL SPATIAL SKILLS

<table>
<thead>
<tr>
<th>Level</th>
<th>No</th>
<th>%</th>
<th>No</th>
<th>%</th>
<th>No</th>
<th>%</th>
<th>No</th>
<th>%</th>
<th>No</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>28</td>
<td>21</td>
<td>50</td>
<td>37.6</td>
<td>63</td>
<td>47.4</td>
<td>20</td>
<td>15</td>
<td>121</td>
<td>91</td>
</tr>
<tr>
<td>Moderate</td>
<td>48</td>
<td>36.1</td>
<td>63</td>
<td>39.8</td>
<td>44</td>
<td>33.1</td>
<td>59</td>
<td>44.4</td>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>Strong</td>
<td>57</td>
<td>42.9</td>
<td>30</td>
<td>22.6</td>
<td>26</td>
<td>19.5</td>
<td>54</td>
<td>40.6</td>
<td>2</td>
<td>1.5</td>
</tr>
</tbody>
</table>

The analysis portrayed in Figure 2 shows that 26.3% of the students did not master all five components in visual spatial skills and only 0.8% dominated the five components of visual spatial skills. On the other hand, majority of the high-achieving students only mastered one component at 31.6%.

Next, as for the level of geometric thinking, it was revealed that almost all the high-achieving students (66.9%) successfully mastered the first level only 24.8% attained the second level of analysis, while almost all failed to reach the third level of informal deduction, as presented in Table 5.
TABLE 5: LEVEL OF VAN HIELE’S GEOMETRIC THINKING

<table>
<thead>
<tr>
<th>Level</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>*L1</td>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>L1 - Visualization</td>
<td>89</td>
<td>66.9</td>
</tr>
<tr>
<td>L2 - Analyze</td>
<td>33</td>
<td>24.8</td>
</tr>
<tr>
<td>L3 - Informal Deduction</td>
<td>1</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*L1 - level below L1

Discussion and Conclusion

Visual spatial skills and geometrical thinking should be highlighted in geometry classes as the objectives outlined by the NCTM (1079). The results of the case study identified the weaknesses in visual spatial skills among high achievers, especially mentally cut, mentally rotation, and mentally view. Meanwhile, the level of geometrical thinking was also at a level of concern, as majority of the students were at level L1, and only 8% were at L3. Form Four students were supposed to be at level L4 (Formal deduction), based on the matrix provided by NCTM (2000). Accordingly, based on the findings of this case study, the present approach of geometry teaching and learning, has failed to emphasize students’ visual spatial skill and geometrical thinking. Therefore, efforts to make improvements in the teaching and learning of geometry should be emphasized particularly in assisting the students to overcome their weaknesses in visual spatial skills and geometrical thinking. Hence, in order to overcome the problem of learning geometry involving 3D, the researcher believes that it is necessary to design and develop meaningful learning using dynamics software called SketchUp Make, which has not been empowered in Malaysian schools for. This notion supports the view of Gutiérrez et al. (2013) and Kurtulus and Uygan (2010) that the integration of multimedia environment which supports 3D and media literacy can accelerate the development of spatial perception. Apart from that, Batistta (2002) also believed that dynamics software can encourage students to move to higher levels of thinking.

References


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