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# Geogebra in Learning of Mathematics Towards Supporting "Stem" Education

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## Abstract

The objective of the study was to identify the effectiveness of GeoGebra's dynamic software application on the work of grade 8 students based on geometric learning areas in Shape and Space, which includes the topics of Pythagoras Theorem, Coordinate, Locus in Two Dimensions and Transformation. At the end of the study, researchers were keen to know whether or not there were evidence of creative and innovative features in the students' works, including skills such as applying, analysing, evaluating and creativity in line with Higher Order Thinking skills (HOTs) in Bloom's taxonomy to support inquiry, exploration, create and reflection within Science, Technology, Engineering and Mathematics (STEM) education. The researchers conducted a quasi-experimental study that consisted of pre-test and post-test to identify the effectiveness of GeoGebra's dynamic software in mathematical learning before and after treatment. A total of 102 students participated in the study. Both quantitative data and qualitative data were collected. The quantitative data was analyzed using MANOVA test. The validity and reliability of GeoGebra's dynamic software manuals and the research instruments were validated by a panel of appointed mathematicians. Meanwhile, the qualitative data was collected through teacher questionnaire, teacher and student interviews, video recording, observation and field notes. The checklist of experimental group's works using GeoGebra's dynamic software demonstrates that the features of HOTs cognitive skills, namely apply, analyze, evaluate, and create had occurred at high frequencies and percentages. This indicates that Shape and Space geometry learning using GeoGebra's dynamic software enables students to create critical, creative and innovative solutions to mathematical tasks that enhances problem solving skills characterized by inquiry, exploration, creation and reflection that support STEM education.

**Keywords:** GeoGebra; Mathematics learning; STEM education; Higher order thinking skills.



## 1. Introduction

STEM Education covers the components of Science, Technology, Engineering and Mathematics, which play a key role in humanitarian, economic growth and technological development through the enhancement of energy, skills and expertise in research and industry. According to National Council of Teachers of Mathematics NCTM (2000), mathematical mastery and technology field became the most important focus for future opportunities and better careers in this global economic era. Therefore, the STEM education, which was introduced in 1967, was again given attention to providing the workforce to develop the country's economy and industry. STEM education is applied in the planning and development of national education that emphasizes on inquiry, exploration, inventions and reflection in problem solving skills in line with the teaching and learning (T&L) objectives in the classroom towards the formation of students' capacity in problem solving, innovative thinking, idea-raising and decision-making capabilities (Felder and Brent, 2016; Ministry of Education MOE, 2016b; National Research Council NRC, 2011).

In this 21st century learning, T&L approach with various media and educational resources provides more opportunities for learning and experience to students to acquire mathematical knowledge through inquiries, exploring knowledge, creating and reflecting on problem solving (Antohe and Antohe, 2014; Lim *et al.*, 2003; Ministry of Education MOE, 2016b; National Council of Teachers of Mathematics NCTM, 2000). To enable L&T processes to be implemented more effectively, depending on technology-intensive educational resources such as GeoGebra's dynamic software, can help students visualize, imagine and master the mathematical concepts that could create meaningful mathematical learning (Effandi and Lee, 2012; Ferdinand, 2011; Jarvis *et al.*, 2011; Royati *et al.*, 2010). GeoGebra's dynamic software is a technology software that helps geometric learning by creating a fun, meaningful, useful and challenging T&L environment, as well as allowing students to acquire mathematical concepts and skills in solving logically and systematically through the process of discovery and experience (Antohe and Antohe, 2014; Effandi and Lee, 2012; Hohenwarter and Lavicza, 2007; Way and Beardon, 2003). In mathematics education, especially geometric fields require skillful and systematic problem solving skills and applying skills, creative and innovative thinking, idea-generating skills and accurate decision-making in order to address mathematical problems in daily life (Ferdinand, 2011; Ministry of Education MOE, 2011; Shriki, 2010). Interactive educational resources such as GeoGebra's dynamic software are needed to realize this challenging learning. Similarly, STEM education, with inquiry, exploration, inventions and reflection features, involves creative thinking

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processes out of the box, exchanging ideas and learning in an inquiry leading to innovation. The creativity emphasized in mathematical learning is a natural feature of human beings that can be enhanced through various exercises, but creativity can be reduced even if it is blocked by teachers who have a more restrictive teaching environment (Langrall *et al.*, 2002; Ministry of Education MOE, 2014;2017). Hence, in T&L, teachers need educational resources such as GeoGebra's dynamic software to help students analyze, understand mathematical facts and theorems when generating new concepts of understanding and subsequently interpreting information and making conclusions based on the results of analysis made (Antohe and Antohe, 2014; Effandi and Lee, 2012; Ministry of Education MOE, 2011) because this ability is important to assist in the development of other skills in the form of higher concentration levels (Langrall *et al.*, 2002; Ministry of Education MOE, 2014;2017).

STEM education contributes towards creating a community with STEM literacy and provide a highly skilled STEM workforce that can contribute to new innovations. According to a study by the National Maths and Science, it is found that the market demand for STEM is steadily increasing compared to non-STEM disciplines. Computer-related work requiring mathematical expertise and problem-solving skills has increased by 45 per cent during 2008 to 2018. Although STEM education has been a significant influence in the world's market economy, the students understanding mathematics has decreased significantly. According to a study by the National Research Council, statistical year-end statistics showed that 75 percent of grade eight students in America did not master mathematically in the year. Similarly, in Malaysia, the number of students who choose the STEM subjects in school is decreasing. In 2014, only 45 percent of students chosed STEM subjects, and the inclination of students not to choose the STEM subjects had increased by 15 percent. The decline in the number of students taking the STEM education trend could distort the intent of achieveing the ratio of 60:40 (science: non-science) by 2020, which was voiced by the Ministry of Education Malaysia would still be lagging behind.

Technology integration in T&L and the implementation of problem-solving approaches will be the inspiration for STEM education because the use of technology resources in T&L is a pedagogical method that interacts directly with the pupil's interest in mathematical learning and for developing creative and innovative thinking and empowering pupils to address mathematical problems so that they are able to compete at the global level through TIMSS international assessment (Ministry of Education MOE, 2013a;2013b;2016a; Mullis *et al.*, 2016), but the use of technology has not been holistic in T&L. The MOE report for 2013 explains that the percentage of teachers using dynamic software is very low at 1.20% and in 2012 is 0.00% throughout Malaysia. Similarly, the analysis results of questionnaires, administered by researchers on a group of 31 mathematics teachers, found that the level of GeoGebra's dynamic software usage in Mathematics T&L among teachers was low, with a mean score of 2.13 and standard deviation is 0.806. Regrettably, even teachers who had attended GeoGebra's dynamic software workshops did not used this software in theid daily T&L. The mean of GeoGebra software usage among these teachers is 1.71, with a standard deviation of 0.902. The result of the pilot study on 78 grade 14 students shows that none of the students demonstrated creative and innovative features in their school works.

Students studying mathematics via conventional approaches and solving mathematics routine questions will usually imitate the ways their teachers' indications during the 'chalk and talk' teachings in the classrooms (Ruzlan, 2006). Additionally, School Based Assessment results showed that students' creative, innovative and creative works did not show high levels of achievement. Students' ability is limited to solving routine exercises and answering questions as instructed by their teachers. Students' level of ability to articulate creative and innovative thinking in geometry is also low. In addition to the lack of technology software usage in mathematics T&L, the level of students' ability in the application and reasoning skills in HOTs is also low.

Trends in International Mathematics and Science Study (TIMSS) results from 1999 to 2015 indicate that the achievement of eighth grade Malaysian students (age 14) in geometric and cognitive reasoning domain is below the nder international significance (Ministry of Education MOE, 2016b; Mullis *et al.*, 2016). In TIMSS 2011, students' cognitive skills were low whereby reasoning skills only reached 32.93 per cent and application skills 37.95 per cent as compared to 45.42 percent for the knowledge aspect. These low cognitive levels indicate that the student's thinking has not yet reached the HOTs cognitive level for geometric learning and less organized, logical and systematic (Ministry of Education MOE, 2014; Pierce and Stacey, 2011; Way and Beardon, 2003). In 2015, the TIMSS results showed that 21 out of the 39 countries worldwide (53.85 percent) were below the minimum benchmark and only 5 percent of students have skills in applying and solving problems. 20 participating countrieshad this low achievement. This includes Malaysia, which has geometric achievements under international minimum benchmarks. The students' ability in the field of geometry, and making association of the forms and features necessary for the solving mathematical problems involving geometry in daily life, has yet to reach the international level.

The study of Iranzo and Fortuny (2011) demonstrated that the usage of GeoGebra's dynamic software can help students to visualize mathematics problems in the context of learning geometric problem solving. Mathematical thinking in geometry can be formed through visualization and the construction algebraic concepts. Multiple representational symbols that are easy to understand in learning geometric concepts can be used to create each concept. According to Pierce and Stacey (2011), teachers' teachings becomes more challenging to ensure students aged 14 and 15 years to understand mathematics because mathematics learning at the secondary level is abstract. Therefore, GeoGebra's dynamic software is deemed appropriate to provide a clearly connect their classrrom learning to the real world through visualization, colour and animations. For instance, nature and environmental buildings can be attributed to digital images in graphical display of GeoGebra's dynamic software to recognize the names and characteristics of geometric shapes, and thus the students' creative and innovative thinking is developed to create conceptual connections and build a new concept understanding. The effectiveness of using GeoGebra's dynamic software in solving mathematics problems that requires creative and innovative thinking is also acknowledges by Hohenwarter and Lavicza (2007), Ljubica (2009), Jarvis *et al.* (2011).

## 2. Methodology

The researchers conducted a pre-test and post-test quasi-experimental study. Quantitative and qualitative data were collected. Quantitative data was collected from the pre- and post-tests. The test instrument consisted of Topical Test (TT) and Spatial Visualization Ability Test (SVAT). TT items were adapted from the TIMSS 1995-2011's items as well as from the Mathematics textbooks to test students' ability in learning Shape and Space before and after treatment. Meanwhile SVAT is adapted from Newton and Bristoll (2015)'s questionnaire entitled Spatial Ability Psychometric Success to test the power of the students' imagination and ability to shadow the combination of shape or change of position 2D and 3D shapes. In addition, other instruments such as the Teaching and Learning Observation Evaluation Instrument and the HOTs Implementation Instrument in Mathematics T&L, adapted from the Ministry of Education Malaysia, were also used to identify the quality of teachers' lessons delivery. Student Workflow Checklist Form was used to track studetns'' work achievement with regards to high cognitive skills, namely applying, analyzing, assessing, and creating. Qualitative data was collected from teacher and student open questionnaires, teacher and student interviews, video recording, field notes, observations and students' work transcripts. Qualitative data was cited to support quantitative data confidence (Creswell, 2008; Noraini, 2013). The sample consisted of 102 grade 8 students from three separate classes and selected according to the class distribution system determined by the school. The researchers chose Grade 8 students because Grade 8 students (14 years old) are involved in TIMSS.

The students were divided into three groups (Experimental Group 1, Experimental Group 2 and Control Group). Experimental Group 1 students and Experimental Group 2 were given treatment using GeoGebra's dynamic software while the Control Group pupils were conventionally taught. The researchers had planned and executed intervention sessions to ensure teachers master the use of GeoGebra's dynamic software. The researchers had also developed a GeoGebra Dynamic Software Handbook that was used by experimental groups 1 and 2 teachers and students. The quantitative data obtained from students' achievement scores in TT and SVAT, T&L observation results, T&L assessment results in terms of application of HOTs elements and student workflow checklist were analyzed. Qualitative data was collected through interviews with teachers, interviews with control group students, interviews with Experimental Group 1 and Experiment Group 2 students. In addition to interviews, the researchers also performed observations, field notes and video recording on the actual T&L sesions and students' involvement in learning activities. The validity and reliability of the instruments were evaluated by mathematicians, whereby the Cronbach Alpha values obtained were .92 for the Topikal Test instrument, .953 for Spatial Visualization Ability Test and .883 instruments for GeoGebra Dynamics Software Handbook developed by the researchers.

## 3. Analysis and Findings

### 3.1. Quantitative Analysis

Quantitative data was analyzed using the Multivariate Analysis of Variance Test (MANOVA) SPSS version 20. The MANOVA test was used to identify relationships between independent variables (the use of GeoGebra's dynamic software) and dependent variables (achievement of student scores in TT and SVAT) by controlling other factors (control variables of students' interest in mathematics) that also affects the dependent variables. The mean value, standard deviation and percentage are used to identify the scores distribution T&L of Teacher 1, Teacher 2 and Teacher 3, HOTs support in mathematics T&L delivery, students' work checklists using GeoGebra's dynamic software.

The data filtering process of the study involved carrying out the linearity test and homogeneity of variance test, which wetre implemented to ensure the suitability of using MANOVA test in the data analysis (Chua, 2014).

In this study, there are two dependent variables namely the achievement of student scores in the TT and achievement of student scores in SVAT. The data filtering process ensures that the dependent variable pairs are linearly correlated and the variance values for the two dependent variables across all the groups within the free variables are the same. The form of the scatterplot graph for the variable pairs relying on pre-test and variable pairs relying on post-test is linear. This shows the the linearity of the data in this study is fulfilled and is scattered near the axis between the TT and the SVAT. Hence, the relationship between the two dependent variables (students' achievement scores in TT and SVAT) in each group of respondents is linearly correlated and should be analyzed using the MANOVA test. The results of Levene's test of Test of Equality of Error Variances show the significance value of before and after treatment for Topical Test [FPre (2, 99) = 8.12, FPost (2, 99) = .24, p> .05] and SVAT [FPre (2, 99) = 1.58, FPost (2, 99) = .41, p> .05] is insignificant. Thus the variance values for both dependent variables across each set of independent variables in the study population are the same. So the MANOVA test is to be continued.

Statistical analysis showed that the TT and SVAT post-test mean scores for the Experimental Group 1 (received treatment), Experimental Group 2 (received treatment) are better than Control Group. The post distribution of the post-test for TT in Experiment Group 1 is 14.75, Experiment Group 2 is 14.36 and Control Group is 7.08, whereas the post distribution mean for SVAT in Experiment Group 1 is 14.50, Experiment Group 2 is 14.36 and Control Group is 7.08. The results of the checklist of student work from the group that used GeoGebra's dynamic software, that is 33 students from Experimental Group 1 and 35 students from Experimental Group 2, showed the existence of the high cognitive levels of HOTs features (applying, evaluating, analyzing, and creating) and a high frequency and percentage (96.21 percent). This serves as evidence that the learning of Shape and Space using GeoGebra's dynamic software enables students to create critical, creative and innovative solutions to the given tasks, depending on their capabilities and abilities as indicated by their mathematics teachers in questionnaires, whereby 71.43 percent of teachers agree and 28.57 percent of teachers strongly agree that the use of ICT in mathematics' T&L is suitable for students with different cognitive abilities.

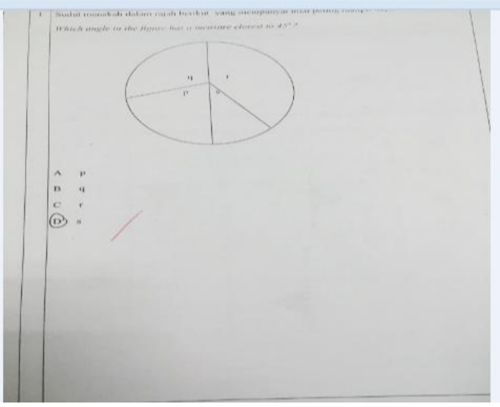
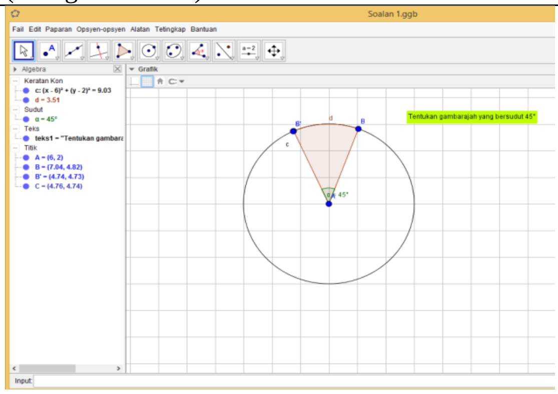
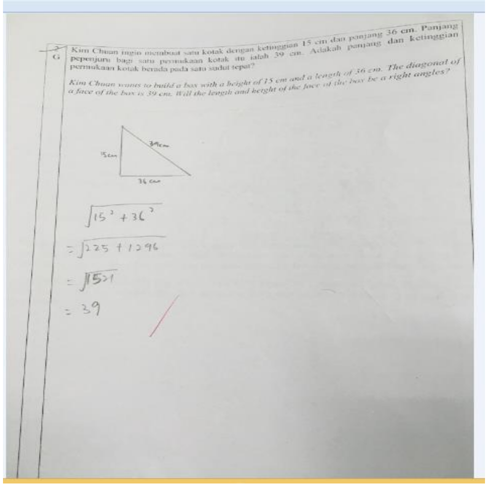
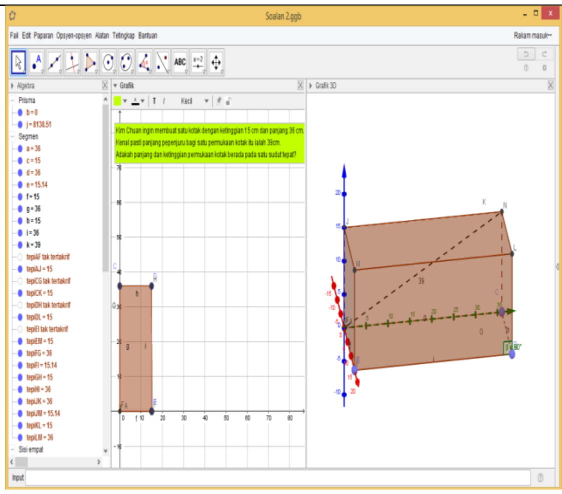
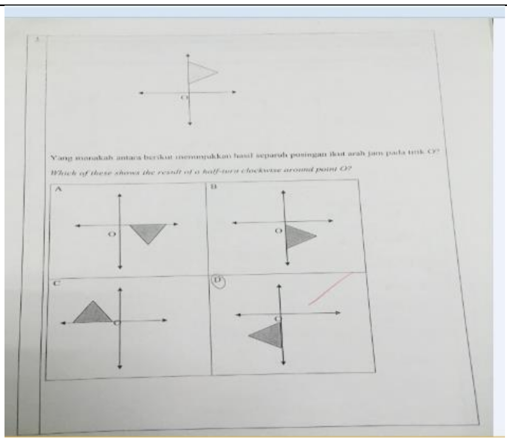
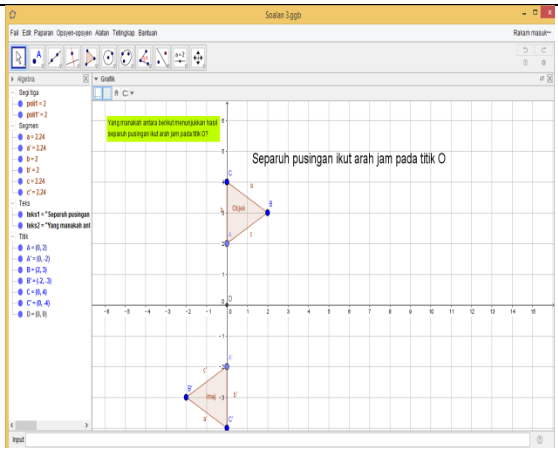
### 3.2. Qualitative Analysis

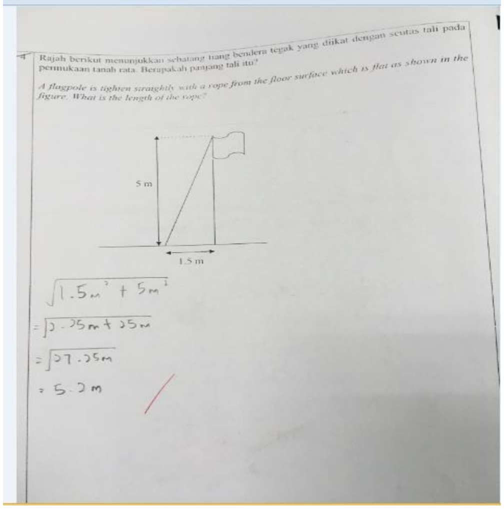
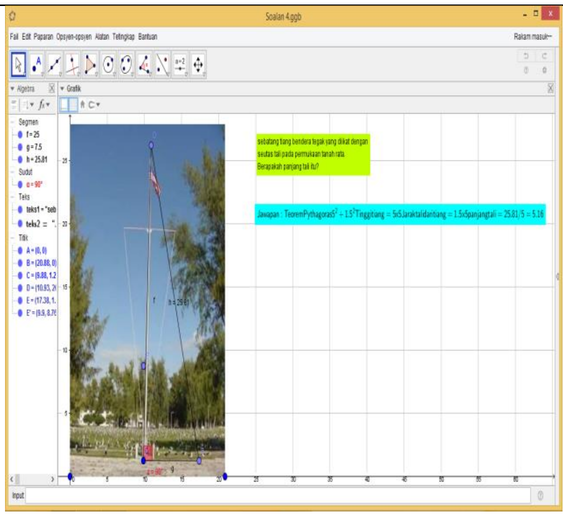
The qualitative data, obtained via analysis of studetns' work transcripts, views of teachers and students as well as aspects of observations of conventional T&L approaches and approach to T&L using GeoGebra's dynamic software, was thematically analysed. The results showed that all six pupils of the Experimental Group 1 and the six Experimental Group 2 exhibited interest in learning mathematics because the use of GeoGebra's dynamic software in geometric learning was able to test their minds and allow them to think and make connections between the concepts of Shapes and Spaces with daily life practices. Students also viewed that the use of GeoGebra's dynamic software is something new to them and is an exciting mathematical learning approach as they have the hands-on opportunity to learn mathematics using ICT. Animation movements, 3D polygon forms of presentations, interlaced images, and colorful display can help them to better understand the concepts of Shapes and Spaces, attracting them to apply, explore and invent new learning. They also "feel good and can talk to peers and feel free to ask questions to their teachers during T&L process". Students proposed learning using GeoGebra's dynamic software is an advantage because "teachers' explanations are easier to understand and are more meaningful compared to their explanations when using chalk and talk T&L approach". The students further commented that "teachers had to erase previous works on the board and had to redraw the diagrams whenever they need to repeat and clarify their explanations". Using the software had actually given them "the opportunity to express creative and innovative ideas for solving problems using HOTs". Hence, students felt confident to produce quality, creative and innovative solutions to the given problems.Students too had voiced their expectation that "GeoGebra's dynamic software continues to be used learning other topics and also extended to be used in co-curricular activities as well beyond T&L to realize STEM Education". Noteworthy, STEM education emphasizes inquiry, exploration, inventions and reflection approaches in problem solving skills. Inquiry, exploration, design and reflection approach in STEM Education is a process of learning through experience and discovery.

The students in the control group, on the other hand, had thought of mathematics as "a counting subject". They learn mathematics with pencils and paper only and memorize the calculations shown by teachers. Throughout the T&L process, the students simply wrote notes and practiced or drilled in accordance with the steps and procedures as indicated by the teacher. This conventional approach had resulted in the feeling of boredom among the students and they were unable to focus on learning. They too were less able to relate their learning to their daily life practices. They did not what to ask their teachers to help them understand the subject matter. They have no idea on how to produce creative and innovative solutions to the given problems.

Figure 1 illustrates the work of a student from the Control Group after following T&L via conventional approaches that is using pencil, ruler and geometric equipment sets. In T&L process designed by teachers, students were given the opportunity to conduct learning activities with diverse educational resources to stimulate the senses of sight, hearing, smell, taste and touch. Pupils perform activities individually, in pairs or in groups by discussing and experiencing each activity process by attempting multiple times to obtain the certainty of solving the problem logically and systematically. With the use of GeoGebra's dynamic software in mathematical learning, students have the opportunity to perform individual computer activities to find information, questioning teachers and friends, looking for similar features in phenomena that occur in the environment to make generalization. For example, the solution to Question 4 (Figure 1), the student explores and associates the phenomenon of daily life with the requirements of the question, obtains the same characteristics and then applies the knowledge about the characteristics of the lines and angles in the relationship between the height of the flagpole and the flat surface. At the end of the lesson, students have the opportunity to generalize the concept of Pythagoras theorem in solving problems related to daily life, as Pierce and Stacey (2011) point out in their study involving secondary school mathematics learning with the use of GeoGebra's dynamic software. Teacher delivered algebraic lessons and functional equations with these dynamic technology software resources for students to make a clearer connection to the use of mathematics in solving daily life problems. The use of GeoGebra's dynamic software had helped students to visualize the problem in the given mathematics problems using imagination that focused more accurately on the issues raised in the question. As conjectured by Iranzo and Fortuny (2011), GeoGebra's dynamic software forms geometric thinking in terms of visualization skills, conceptual understanding and accurate algebraic mastery.

**Figure-1.** Comparison of student answers between conventional approaches and the use of GeoGebra's dynamic software.

| | Control Group (Conventional approach) | Experimental Group (Using GeoGebra) |
|---|---|---|
| Q1 |  |  |
| Q2 |  |  |
| Q3 |  |  |

| | | |
|---|---|---|
| Q4 |  |  |

## 4. Conclusion

This study has explained the effectiveness of using GeoGebra's dynamic software in learning of Shape and Space among grade 8 student. The results show that the use of GeoGebra's dynamic software in mathematics T&L process enhances students' achievement in responding to Topical Test questions and Spatial Visualization Ability Test. In addition, the work produced by students using GeoGebra's dynamic software has shown HOTs' elements and incorporates STEM education features. GeoGebra's dynamic software plays an important role in geometric learning in terms of theoretical and conceptual understanding through visualization in two and three-dimensional forms (Hohenwarter and Lavicza, 2007; Iranzo and Fortuny, 2011; Ljubica, 2009). Inquiry, exploration, design and reflection skills to solve problems and decide, innovate and foster students' creativity and innovation thinking in geometric learning can be integrated with the use of GeoGebra's dynamic software. The geometric learning process is carried out in stages according to the student's cognitive development as outlined in Van Hiele theory. In fact, the visualization and imaginative forces formed by Piaget's theoretical sequence of concrete to abstract help geometric thinking be constructed logically and systematically in dealing with mathematical problems and making reasonable decisions in daily life (Philips *et al.*, 2010). Educators and educational policy makers need to include GeoGebra's dynamic software in mathematical syllabus as this dynamic technology software can help students visualize, understand and master the mathematical concept more easily and meaningfully. GeoGebra's dynamic software courses, workshops and exercises need to be extended to teachers and students at all stages of school so that the integration of technology into STEM education can be realized. In addition, studies on the effectiveness of GeoGebra's dynamic software need to be researched further as the current researchers had focused only on the teaching of the teaching of Shape and Space for grade 8 students at a daily secondary school in Peninsular Malaysia.

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