GeoGebra: Towards Realizing 21st Century Learning in Mathematics Education

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ABSTRACT

Purpose – This study examines the effect using GeoGebra dynamic geometry software on students' ability to confront geometry problem solving, their achievement in spatial visualization skills, and their usage of cognitive skills in applying, analyzing, evaluating, creating and constructing ideas for geometry problem solving on the topic of Shape and Space towards supporting 21st century learning of Mathematics Education.

Methodology – Quantitative and qualitative data were collected for this study. A total of 102 Form Two students participated in the study, which had employed the pre-test and post-test quasi-experimental research design. The research participants were divided into three groups, namely Experimental Group 1 (n=33), Experimental Group 2 (n=35) and Control Group (n=34). A guideline book on using GeoGebra dynamic geometry software in learning of Shape and Space, developed by the researchers and validated by a panel of experts, was used by the teachers and students in the experimental groups. The quantitative data, obtained via the Topical Test (TT) and Spatial Visualization Ability Test (SVAT), were analysed using MANOVA. The reliability coefficients of TT and SVAT were 0.972 and 0.953 respectively. The qualitative data, collected via interviews, teaching observations, video recordings and students' works, was thematically analysed.

Findings – The experimental groups' TT and the SVAT post-test mean scores for both the experimental groups were significantly higher than the control group's TT and the SVAT post-test mean scores. The learning of Shape and Space using GeoGebra dynamic geometry software had enabled students to produce works with evidence of critical, creative and innovative elements in their solutions. The experimental groups' students agreed that using the dynamic software something new to them and was indeed as an attractive way to learn mathematics because they had the opportunity to experience hands-on learning of mathematics using ICT. They voiced their dessire to also use the GeoGebra dynamic geometry software when learning other mathematics topics.

Significance – The use of GeoGebra dynamic geometry software to support the notion of integration of technology in the teaching and learning of mathematics in schools has the potential to promote active students involvement in mathematics learning. The active learning could provide students with meaningful learning experiences and opportunities to produce quality, creative and innovative works. The dynamic software has the capacity to support students' logical and systematic approaches in solving geometry problems and also triggers multiple ways of interactions and collaborations in the mathematics classrooms. The stimulation of students' creative and innovative thinking provide evidence for the potential support of the dynamic software towards realizing 21st century learning within Mathematics Education.

Keywords – GeoGebra, Mathematics Education, creative and innovative, shape and space, 21st century learning

INTRODUCTION

21st Century Learning is a global education transformation that encompasses 21st century skills, higher order thinking skills, high information and technological skills, problem solving, innovative thinking, generating multiple ideas and decision making skills that can be inculcated in teaching and learning that emphazises knowledge, skills and values in confronting everyday problems logically and systematically (Saavedra, Opfer, 2012; MOE, 2013c; MOE, 2017). In addressing 21st century learning, students need to have the capability to apply the knowledge they acquired to solve problems and to confront non-routine experiences. 21st century learning practices prepare students to face greater global learning challenges which include their participation in international assessment such as Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student

Assessment (PISA). The conventional chalk and talk approach, that involves only memorising of formulas and transferring arithmetic strategies from the board onto the answer scripts, is taken as an old approach and is less relevant to the 21st century students' needs (Saltrick, Hadad, Pearson, Fadel, Regen, & Wyan, 2011; Saavedra & Opfer, 2012; MOE, 2017).

According to a study by National Education Association (2010) and Partnership for 21st Century Skills (2011), the four most important specific skills in 21st century learning are critical thinking, communication, collaborative, creative and innovative (4C). Critical thinking skills as well as creative and innovative skills are the higher order thinking skills (HOTS). The applying, evaluating, analysing and creating cognitive skills include non-routine problem solving activities as well as making logical and systematic reasoning (Saltrick, et al., 2011; MOE, 2013c). To confront global learning issues, such as TIMSS and PISA, every student must have the ability to apply their knowledge when solving problems and feel confident to face non-routine problems.

The conventional chalk and talk approach to teaching mathematics, that promotes rote learning of rules and formulas and the transfer of solution strategies from the board to papers, is considered as an old approach which is less relevant to the needs of 21st century students (Saltrick, et al., 2011; Saavedra & Opfer, 2012; MOE, 2017). The TIMSS results from 1995 to 2011 indicated a decline in mathematics achievement among 44% grade 8 students who were involved in the TIMSS studies. These students were weak in applying and reasoning skills in the domain of geometry (Mullis, Martin, Michael, Foy, & Arora, 2012; MOE, 2013b; MOE, 2016) due to lack of interest, low level of confidence in mathematics learning and the lacking of ICT usage in teaching and learning mathematics (Mullis, et al., 2012; MOE, 2013b; MOE, 2016; Mullis, Martin, Foy, & Hooper, 2016). Among these students, 31% were reported to have no interest in mathematics and 41% of them lacked confidence in learning mathematics. The use of computer softwares was low and was used only for explanation of basic mathematics (7%), teaching and learning (55%), exploring mathematics concepts and facts (22%), and training of mathematics process skills (24%) (Mullis, et al., 2012).

The integration of technology in teaching and learning can ensure 21st century learning that contribute towards the development of critical, creative and innovative thinking through the application, restructuring and reasoning in solving everyday problems (Way, & Beardon, 2003; Lim, Fatimah, & Munirah, 2003; Saavedra & Opfer, 2012; MOE, 2017). One such resource for technology integration is the GeoGebra dynamic geometry software. This dynamic software is a type of technology software that can be used, without any cost, to learn topics such as algebra, geometry, calculus and statistics. It supports the learning of mathematics concepts for the purpose of acquiring effective problem solving skills and can assist students in understanding processes of mathematics theories and facts through pictorial visualization in two and three dimensions (Hohenwarter, Lavicza, 2007; Ljubica, 2009; Royati, Ahmad Fauzy, & Rohani, 2010; Jarvis, Hohenwarter, & Lavicza, 2011; Effandi, & Lee, 2012). It is also an interactive geometry system that can be utilised to construct lines, angles, function graphs, locus, circles, polygons, vectors, transformations, geometrical constructions and solid geometry for the purpose of geometry learning (Jarvis, Hohenwarter, & Lavicza, 2011; Effandi & Lee, 2012; Antohe, & Antohe, 2014). Interestingly, GeoGebra dynamic geometry software has four displays, namely algebra, 2D graphic, 3D graphic and statistics, simultaneously on one screen. In geometry learning, students have the opportunity to concurrently learn 2D and 3D graphic shapes when working on algebra problems using technology resources. Saavedra and Opfer (2012) conjectured that technology resources have the potential to develop students' critical thinking, problem solving capabilities and innovative thinking skills.

A study by Kamariah, Ahmad, and Rohani (2010) indicate that GeoGebra dynamic geometry software can be used as a supporting tool to construct new concepts in the topic of Transformation. They had recommended for the extension of studies with regards to the use GeoGebra dynamic software on other secondary school mathematics topics to further establish its effectiveness. On a similar note, Chacon and Prieto (2010) believe that GeoGebra dynamic geometry software is a technology software that is really efficient in assisting teacher trainees to solve mathematics problems. However, there is no appropriate guideline books pertaining to the use of GeoGebra dynamic geometry software in mathematics learning. This had prompted the researchers to pursue the current study by first developing a guideline book on the use of GeoGebra dynamic software in learning Shape and Space, a book that can also be used by mathematics education undergraduates, teacher trainees at teacher training institutions or colleges, teachers and students.

PROBLEM STATEMENT

Malaysia's achievement in TIMSS 2015 was better compared to its achievements in TIMSS 1999 until TIMSS 2011. Despite its better achievement in 2015, Malaysia, together with 79% of other countries, was still below the minimum international benchmark. Statistics showed that 84% of students who participated in the study were still at the acquisition of basic mathematics level and they were lacking in critical, creative and innovative thinking (MOE, 2016; Mullis, et al., 2016). They were also weak in the aspects of recalling knowledge, applying knowledge of mathematics to solve problems and reasoning skills in problem solving. Generally, among the international assessment participants, and within the cognitive domain, they were very weak in applying and reasoning skills. Consequently, this had constituted a constraint for geometry learning.

In Malaysia, only 32.93% of the students acquired the reasoning skills, compared to 37.95% who acquired the knowledge skills and 45.52% who acquired the knowledge skills in geometry learning and this low achievement in the acquisition of cognitive reasoning skills had contributed to the low critical, creative and innovative skills among them (MOE, 2013). The use of GeoGebra dynamic software could be an alternative teaching approach to help overcome this issue because using this dynamic software as a technology education resource in teaching and learning students' can enhance student's critical, creative and innovative thinking (Hohenwarter & Lavicza, 2007; Iranzo, & Fortuny, 2011; Antohe & Antohe, 2014). Conventional teaching approaches, one-way delivery teachings, passive students involvement, questioning activities involving routine problems and drilling exercises involving routine items is seen incapable to fulfill the needs of the challenging 21st century global learning (Satrick, et al., 2011; MOE, 2013b).

Presentation of lessons using the chalk and talk approach without using supportive resources, especially technology resources, could cause inappropriate understanding among the students and teaching and learning sessions that are less attractive in this era of technology (Way & Beardon, 2003; Lim, et al., 2003; Pierce & Stacey, 2011). According to the Inspectorate and Quality Assurance Board (2013), the percentage of technology supported resources usage in teaching and learning was very low. In the year 2013, the percentage of teachers using dynamic geometry software in the whole of Malaysia is incredibly low (1.2%), and in 2012 it was 0.00% (MOE, 2012; MOE, 2013a). In a preliminary survey carried out by the current researchers prior to the implementation of the current study on 31 mathematics teachers, it was found that the mean score of teachers using GeoGebra in their teaching and learning of mathematics was 2.13 (SD = 0.806) and for the teachers who had attended workshops or trainings on GeoGebra, the mean score for using GeoGebra was 1.71 (SD = 0.902).

The various advantageous of using GeoGebra dynamic geometry software in geometry learning, the development of critical thinking, generating multiple ideas, creativity and innovation in 21st century education, the low rate of using ICT in mathematics teaching and learning and the low rate of using GeoGebra software partly formed the impetus for the current researchers to design a guideline book entitled 'Guideline for Using GeoGebra Dynamic Geometry Software in the Learning of Shape and Space", and to pursue a study on the use of GeoGebra dynamic geometry software in the learning of Shape and Space among Form Two students. It is hoped that the current study, with the guideline book as well as the findings, could contribute to the advancement of Mathematics Education. Additionally, the study could also beneficent the Ministry of Education and other relevant organizations and parties to design teaching and learning workshops for the advancement of mathematics teachers' competencies and professional skills to deliver meaningful based mathematics teaching and learning activities in mathematics classrooms.

RESEARCH OBJECTIVES

The study was carried out to determine the effect of using GeoGebra dynamic geometry software on students' achievement ia a Topical

Test (TT) that tests students ability to answer HOTS items based their learning area of Shape and Space. This learning area encompasses the topics of Pythagoras Theorem, Coordinate, Locus in Two Dimensions, and Transformation. Their achievement was measured before and after undergoing learning of the area using the aforementioned dynamic geometry software. The researchers also determined the effect of using the dynamic software on students' spatial visualization ability. Additionally, the researchers had identified the existence of evidence of creative and innovative elements within the works that the students produced. The teachers and students views regarding the implementation of traditional lessons as well as lessons that had incorporated the use of GeoGebra dynamic geometry software were also explored.

LITERATURE REVIEW

Jarvis, Hohenwater & Lavicza (2011) point out that there is a trend in using the GeoGebra dynamic and interactive geometry software globally since its first introduction in 2002. They also assert that students learn mathematics better with the use of this dynamic technology software which is capable of doing these three things, namely, make mathematics teaching and learning sessions become more attractive, improve students' attitude, and stimulated their motivation to learn mathematics, nurtured students' thinking to be more critical, creative and innovative towards solving mathematics problems in a more logical and systematic manner.

The advantageous of using the GeoGebra dynamic geometry software had gained alarming support throughout the world and as a result of this many GeoGebra institutes has been established in most developed countries such as United Kingdom and the United States. It can be seen that there are countries that have been taking steps to develop and extend the use of the GeoGebra dynamic geometry software globally towards supporting the demands of 21st century learning. The view of Jarvis, Hohenwarter and Lavicza (2011) is in line with the findings of Wurnig (2009), who found that students had gained new experiences when learning to understand the conic concept and graph function by using this dynamic software. Wurniq (2009) also argues that students' own pictures and pictures of everyday live activities can be inserted in the GeoGebra graphic display and subsequently they can relate these pictures to the learning of conic and function equations which involve cognitive analysis, evaluating and creating skills. The usage of GeoGebra dynamic geometry software initiated effective and meaningful learning among the students and consequently prompted them to increase their efforts to systematically solve the given mathematics problems.

A qualitative case study on the influence of GeoGebra on problem solving strategies was carried out by Iranzo and Fortuny (2011). They had found evidence of the use of GeoGebra dynamic geometry software in Euclidean learning approach and problem solving. These students had thought critically, creatively and innovatively, and they had also collaborated and communicated efficiently among their peers. Students without the experience of using GeoGebra dynamic geometry software had worked cooperatively within the group to visualize the mathematics problems. The students were also able to self-organize the operations of GeoGebra dynamic geometry software to accurately visualise the mathematics problems given to them, which consequently initiate their geometric thinking in problem solving. Undoubtedly, the use of GeoGebra dynamic geometry software had initiated the students to construct various representations to manifest their understandings of geometry concepts. The use of this dynamic software had also assisted the students in overcoming the issues related to their understanding of algebra for the acquisition of geometry concepts. More importantly, the use of this dynamic geometry software had enabled the students to learn various problem solving approaches to tackle or face everyday live experiences.

METHODOLOGY

Research Design

The study had employed the quasi-experimental research design (Creswell, 2012). The participating students were divided into three groups, namely Experimental Group 1, Experimental Group 2, and Control Group. Students in the Control Group were taught Shape and Space using the conventional approach using pencil, paper and geometry equipment. The delivery of the lessons were in the form of chalk and talk. Students in the control group were given the pre-test before the topics were taught. They completed the post-test using pencil and geometry equipments only. Students in the two experimental groups answered the post-test upon completion of the intervention period using GeoGebra dynamic geometry software.

Students in both the experimental groups received treatment in the form of teaching and learning activities using GeoGebra dynamic geometry software. Two mathematics teachers had taught the two experimental groups.These teachers were trained by the researchers to provide the skills on using the GeoGebra dynamic geometry software based on the book 'Guideline for Using GeoGebra Dynamic Geometry Software in the Learning of Shape and Space'. This guideline was designed and developed by the researchers. In the current study, the researchers did not give any prior treatment to the students in the control group.

Sample

A total of 102 Form Two students (average age 14 years) had participated in this study. They were from three different classes and were selected following the school's fixed classes arrangement system. Form Two students were selected because for the international assessment test (TIMSS), the measurement of mathematics learning acquisition among students in Malaysia involve students around the age of 14 years old (grade 8) to benchmark against the achievement of students from other participating countries. Moreover, these Form Two students have prerequisite knowledge in geometry area and were taught the topic on Shape and Space as outlined in the Form Two Mathematics syllabus.

All the three groups had similar level of mathematics achievement at the start of the study. The result of the pre-test [Topical Test (TT) and Spatial Visualizatioan Ability Test (SVAT)], show that the three groups had almost similar scores, whereby the mean score obtained for each of the groups area as follows: for 34 students from the Control Group was: TT = 5.79 and SVAT = 6.08; for 33 students from Experimental Group 1 was: TT = 5.54 and SVAT = 6.77; and for 35 students from Experimental Group 2 was: TT = 5.28 and SVAT = 5.50. Three teachers (Teacher-1, Teacher-2 and Teacher-3) had agreed to be involved in the study.

Instruments

The instruments used in the current study were the Topical Test (TT), the Spatial Visualization Ability Test (SVAT), and the Teaching and Learning Observation checklist. TT was comprised of items that were adapted from the TIMSS 1995 – 2011 as well as from the text books. A total of 20 items were included in the TT with 35% of them testing the knowledge cognitive level, 40% testing the applying cognitive level and 25% testing the reasoning cognitive level. The evaluation of the suitability of the test items was done by a panel of experts. The Cronbach Alpha value for TT was .92. According to Bloom's Taxonomy, the applying cognitive level and the reasoning cognitive level are the higher order thinking skills which consequently contribute to the creative and innovative thinking skills.

The Spatial Visualization Ability Test (SVAT) was another instrument used in the current study to determine the effect of GeoGebra dynamic geometry software on students' spatial visualization ability. SVAT was adapted from *Spatial Ability Psychometry Success* which was developed by Newton and Bristoll (2015). The SVAT items were also evaluated by a panel of experts. The Cronbach Alpha value for SVAT was .953. There were 20 items in SVAT which measured students' ability to perform two dimensional visual comparisons, to visualize group rotation in two dimensional formats, to visualize combination of two dimensional shapes, to visualize three dimensional cube shapes and to visualize cube in two and three dimensional format.

The instrument used to measure the implementation of HOTS in the mathematics classrooms was the Teaching and Learning Observation Form which was taken from the Inspectorate and Quality Assurance Board, Ministry of Education. This instrument were constructed based on the 12 aspects of teaching and learning indicated within the 2010 Malaysia Education Quality Standard. In the Teaching and Learning Observation instrument, HOTS was determined by measuring the following aspects: teacher's delivery and approach, questioning technique and students' works. Students' Works Checklist was used to evaluate the cognitive level of the experimental groups' students' works. This checklist helped to identify the four highest cognitive skills, namely applying, analysing, evaluating and creating.

Data Collection

The study had collected both quantitative and qualitative data to explore the link between the use of GeoGebra dynamic geometry software and the students' scores in TT and SVAT. The quantitative data were comprised of students' scores in the Topical Test (TT), the Spatial Visualization Ability Test (SVAT), the teaching and learning session's observations, the inculcation of HOTS elements in the process of teaching and learning, and checklist on elements of HOTS in students' works. The researchers also collected qualitative data to support the quantitative data (Creswell, 2008; Noraini, 2013). The teaching observations and evaluations were carried out by the school's Mathematics Panel Head. The students' works were evaluated by the mathematics teachers. The teaching and learning sessions were video-recorded. Semi-structured interviews were carried out with the teachers and the students. These interviews were handled by the researchers. The teaching episodes and the interviews were fully transcribed. Additionally, field notes were also taken by the researchers during the study and included in the qualitative data analysis.

Data Analysis

The quantitative data in this quasi-experimental study was analysed using Multivariate Analysis of Variance Test (MANOVA) to determine the difference in TT and SVAT achievement scores among students who did not received treatment and those who received treatment. The mean values, standard deviation and percentages are used to determine the distribution of the scores for Teacher-1, Teacher-2 and Teacher-3 teaching and learning sessions, support of HOTS in the delivery of mathematics lessons, checklist of students' works that used GeoGebra dynamic geometry software. The data from observations, field notes and video recordings of teaching and learning sessions and students' participations in the teaching and learning activities were also analysed. Qualitative data were transcribed and thematically analysed and categorised to explore and understand the teachers and the students' perception on their experiences with regards to the teaching and learning of Shape and Space using conventional teaching approach and using GeoGebra dynamic geometry software.

RESULT

Quantitative Data

Linearity and homogeneity of variance tests were executed to determine the appropriateness of using MANOVA to analyse the quantitative data (Chua, 2014). The dependent variables in this study were students' achievement in TT and in SVAT. The data cleaning processes ensured that the linearity of the correlation between the dependent variable and the independent variable and that the variance values for both dependent variables throughout every independent variable group were the same. Scatterplot graphs for the pre-test dependent variables pair and post-test dependent variables pair indicates linearity. Hence, this shows that linearity of research data was fulfilled and the data distributed near the axis between TT and SVAT. This means that the relationship between the two dependent variables (achievement in TT and SVAT) in each group shows linear correlations and thus it is appropriate to use MANOVA to analyse the data.

Table 1 shows that the TT and SVAT post-test mean scores for Experimental Group 1 (received treatment), Experimental Group 2 (received treatment) are better than the Control Group (received no treatment). The Experimental Groups 1 and 2 post-test mean scores for TT are 14.75 and 14.36 respectively, whereas the Control Group post-test mean score is 7.08. The Experimental Groups 1 and 2 post-test mean scores for SVAT are 14.50 and 14.36 respectively, whereas the Control Group mean score is 7.08.

Table 1

The Means and Standard Deviations of TT and SVAT

	Students	Mean Score		Standard Deviation		N
		Pre-Test	Post-Test	Pre-Test	Post-Test	
TT	Experimental Group 1	5.54	14.75	2.25	2.18	33
	Experimental Group 2	5.28	14.36	1.20	2.01	35
	Control Group	5.79	7.08	2.02	2.04	34
						102

(continued)

	Students	Mean Score		Standard Deviation		N
		Pre-Test	Post-Test	Pre-Test	Post-Test	
SVAT	Experimental Group 1	6.77	14.50	1.41	2.40	33
	Experimental Group 2	5.50	14.36	1.81	2.01	35
	Control Group	6.08	7.08	1.21	2.04	34
						102

Table 2

Analysis of Students' Works Who Used the GeoGebra Dynamic Geometry Software

Construct	Verb	*f*	%
Applying	Prompt ideas	68	100
Using knowledge / materials / ideas / strategies / concepts / principles / theories in new situations	Estimate	68	100
	Build	68	100
	Solve	68	100
	Make series	68	100
	Practice	68	100
	Differentiate	68	100
Analysing	Breakdown	68	100
Separate information into components to understand and establish relationships between components	Choose	68	100
	Reasoning	68	100
	Make assumption	68	100
	Solve problem	68	100
	Make conclusion	50	73.53
Evaluate	Interpret	68	100
Justify results or actions that had been taken or evaluate ideas / materials / methods based on specific criteria	Critic	68	100
	Conclude	50	73.53
	Make Decision	50	73.53

(continued)

Construct	Verb	*f*	%
Create/ Construct Ideas Combine ideas with creative thinking to produce new ideas / structures	Combine	68	100
	Plan	55	80.88
	Summarize	68	100
	Construct	68	100
	Design	68	100
	Create	68	100
	Conceptualize	68	100
	Make Mental Images	68	100
	Communicate	68	100
	Percentage Mean Score		96.21

Table 2 shows the results of the analysis on students' works who used GeoGebra dynamic geometry software (Experimental Groups 1 and 2). Students solved the tasks using combination of skills (applying, evaluating, analysing, and creating) and had obtained a high frequency and percentage (96.21%). This result provides evidence that the learning of Shape and Space using GeoGebra dynamic geometry software had triggered their critical thinking and enabled them to produce works with evidence of critical, creative and innovative elements. In a survey carried out by the researchers, 71.43% of the teachers had agreed and another 28.57% had strongly agreed that the use of ICT in the teaching and learning of mathematics are appropriate for student with different abilities.

Qualitative Data

Interest Towards Mathematics

The result of the interviews with six students from Experimental Groups 1 and 2 respectively indicate that all of them were interested to learn mathematics because of the opportunity to use the GeoGebra dynamic geometry software for learning of geometry. This dynamic software tested their minds and enabled them to think and make connections between concepts in Shape and Space and their everyday life practices.

Mathematics Learning Approach

Students regarded the use of dynamic geometry software as a new approach and an attractive way to learn mathematics because they were given the opportunity to experience hands-on learning of mathematics using ICT. The animation, presentation of 3D polygon shapes, insertion of pictures, and colourful displays had not only assisted their understandings of Shape and Space concepts but also had boosted their interests to apply, explore and create new learning.

Mathematics Learning Situations in Class / Lab

The students felt the joy of learning and were able to discuss their works with their peers. They too felt free to ask their teachers questions throughout the teaching and learning sessions. The GeoGebra dynamic geometry software was special to them becasue teachers were able to explain the lesson content, which was normally difficult for them to understand, in a clearer way than the chalk and talk explanation. In this conventional approach, almost always teachers has to erase what they had written on the board and then usually redraw diagrams when they need to re-explain the lesson content to the students. The students also felt that the teachers had given them opportunities to materialize their creative and innovative ideas when solving the given mathematics problems. In this sense, the teachers had gave them the opportunities to use higher order thinking skills in confronting their assignments. These opportunities almost certainly is a way forward to realize and support the notions of 21st century learning.

Students' Works and Hopes

The students in this study seemingly were confident to produce solutions to the problems that were not only of better quality but were also creative and innovative. Interestingly, they hoped that they are able to continue using the GeoGebra dynamic geometry software when learning other Mathematics topics. They also suggested that the opportunities to use this software should be extended to co-curricular activities and outside formal teaching and learning sessions so that 21st century learning can be realized. However, the results of the interviews with students from the Control Group indicate that they perveived mathematics as a 'calculation' subject, and that they learned mathematics only through 'paper and pencil tests' whereby they need to memorize the calculation steps or procedures that their teachers demonstrated on the board. Students only wrote notes and solve mathematics problems by imitating the working steps or procedures as indicated by the teachers. Seemingly, the conventional approach to learning Shape and Space had resulted in feeling of boredom among the students and made them loose focus. The students even mentioned that they were not able to figure out the connections between what were taught by their teachers and their everyday life activities. Students were also observed to be less active in the mathematics classrooms. Another aspect of concern here is the fact that these students almost never bother to ask questions in the classrooms. When this questioning issue was raised during the interviews, some of them had responded by saying that they did not understand the content of the lesson, hence they did not know what questions to ask. They lacked ideas to produce creative and innovative solutions to the given mathematics problems. Hence, in a sense, they were not creative and innovative enough to obtain high marks in their mathematics assessment. Table 3 provides examples of responses given by students in the interviews.

Table 3

Examples of Students' Responses in the Interviews

Aspect of Response	Experimental Group 1 Students	Experimental Group 2 Students	Control Group Students
Interest towards Mathematics	1. Interested. Can use in everyday lives. (E1R1) 2. Interested but sometimes feel that Mathematics questions are difficult. (E1R3)	1. Interested. It tests our mind. (E2R4) 2. Interested. Can learn new thing. (E2R6)	1. I don't like Mathematics because cannot understand … confused (KR3) 2. I don't like Mathematics because cannot understand teacher teach (KR4)

(continued)

Aspect of Response	Experimental Group 1 Students	Experimental Group 2 Students	Control Group Students
Mathematics learning approach	1. Understand more when using GeoGebra. Enjoy because there is animation in Locus (E1R1) 2. More attractive. There is animation in Locus (E1R2)	1. Can repeat working steps with GeoGebra (E2R1) 2. Can make 3D shapes (E2R2)	1. Teacher writes steps to solve problems on the board and at the same time explaining the steps (KR1) 2. Teacher writes on the board and we copy only the important notes (KR3)
Mathematics Learning situations in class / lab	1. Enjoy. Can understand better. Friends discuss to learn together. No gossiping and making noises (E1R1) 2. Enjoy because can understand mathematics concepts (E1R2)	1. Enjoy more and more attractive (E2R1) 2. Enjoyed it. Can pay more attention to teacher (E2R2)	1. Boring because teacher is always angry (KR1) 2. Less attractive (KR2)
Student's work	1. With GeoGebra I can think in a creative way (E1R1) 2. More creative by inserting more attractive pictures (E1R2)	1. GeoGebra helps in understanding concepts (E2R1) 2. GeoGebra can help solve problems (E2R2)	1. Never get band six (KR1) 2. Drilling questions only (KR2)
Students hope	1. Hope teacher can keep using GeoGebra because we can see 3D shapes more clearly and easy to understand (E1R1) 2. I hope teacher use GeoGebra because we feel so enjoy to learn mathematics (E1R2)	1. My hope is teacher can do GeoGebra workshop so that can understand more (E2R1) 2. Hope teacher can continue using GeoGebra to teach mathematics (E2R2)	1. Hope teacher uses more teaching resourses so that we can understand… use something we can touch, see, hands on, can moving….. (KR1) 2. Hope teacher use ICT for students to learn mathematics (KR2)

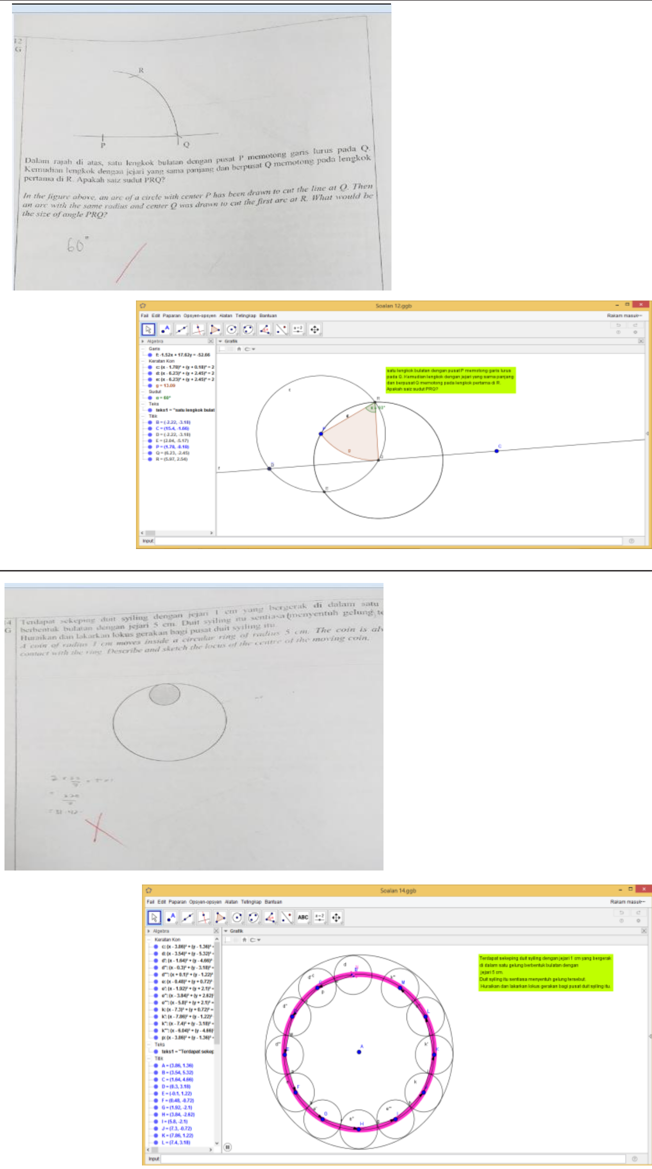

Figure 2 *Comparison of Students Works in the Topical Test*

Figure 2 shows the difference between the experimental groups' students' works and the control group students' works. The figures in the left column show the control group's students' works, who only used pencil and geometry resources to display a routine outcome. The students' ability to solve the given mathematics problem seemingly is limited. The students did not seem to understand what was asked in the problem and did not exactly answer the question. The figures in the right column show the works of students from the experimental groups. They were able to display works that are more attractive which is indicative of their understanding of geometry concepts through visualization in the form of animation movements. The geometric shapes were precisely drawn and students they seems to have learn geometry through clearer mathematical relationships and representations. They were able to logically and systematically solve the given problems.

DISCUSSION

The research findings show that the achievement scores of students from Experimental Group 1 and Experimental Group 2 were higher after receiving treatment compared to their scores before treatment. The result of MANOVA test indicates that the mean achievement score of students from Experimental Group 1 had increased from 5.54 to 14.75. Similarly, the mean achievement score of students from Experimental Group 2 improved from 5.28 to 14.36 compared to the slight increased of the mean achievement score of students from Control Group, which is from 5.07 to 7.08. These findings support Hohenwater and Lavicza (2007) and Ljubica (2009) research results and their conjecture that GeoGebra dynamic geometry software can enhance students' critical thinking ability, their creativity and innovative skills that consequently enhance their visualisation skills and acquisition of geometry concepts.

The research results also show that the achievement score of students from Experimental Group 1 and Experimental Group 2 in the Spatial Visualization Ability Test are higher than their achievement before receiving treatment. This finding is in line with the findings of Haciomeroglu (2011) who concluded that GeoGebra dynamic geometry software potentially enhance spatial visualisation ability when solving mathematics problems that require critical, creative and innovative thinking. The current study also provides evidence of creative and innovative works produced by students from both the experimental groups. These students were able to correctly analyse and evaluate the needs of the questions given to them. They had use their critical and creative thinking skills when applying their prerequisite knowledge to create new concepts in geometry learning. These findings support the findings of Wong (2013) who found that GeoGebra dynamic geometry software could support students in achieving the highest cognitive skills towards higher order thinking skills. Students were also able to think critically, creatively and innovatively towards elucidating new ideas, which are original, continuous, flexible and systematic.

Results from the interviews can be categorised into five aspects, namely students' interest in mathematics, methods of mathematics learning, conditions of mathematics learning in classrooms, production of students works and students aspirations on the use of GeoGebra dynamic geometry software. Students' responses towards the use of this dynamic software in geometry learning were positive. They obtained a clear picture of geometry concepts with the help of the dynamic software which consequently helped them to design systematic solutions when solving the given problems.

The results of the current study provide evidence that the use of GeoGebra dynamic geometry software can cultivate interest among students to learn mathematics, enhance students' visualization ability that help them clearly and correctly understand mathematics concepts, and enhance students' ability to solve non-routine mathematical problems logically and systematically. The integration of technology in 21st century learning has the potential to inculcate four higher cognitive skills among students. These include skills for applying, analysing, evaluating, creating and constructing ideas as highlighted in Bloom's Taxanomy, as described below:

1. Applying

   Applying skill is the ability to analyse information and confront everyday problems logically and systematically in line with 21st century education. This study shows that teaching and learning of Shape and Space using GeoGebra dynamic geometry software as a technology support resource had enabled students to use reasoning and applying skills in line with the aims of mathematics learning. Students had the opportunities to analyse and understand facts and mathematics theorems and use them to generate understanding of new concepts and subsequently interpret information and draw conclusions based on the results of the analysis. By going through the process of operating the GeoGebra dynamic geometry software, students were able to critically reflect and apply the acquired knowledge to solve mathematics problems in manners which are more logical and systematic. This supported the findings of Wumig (2009) and Iranzo and Fortuny (2011) who note that students can understand new mathematical concepts through solving problems that are related to their everyday lives when they use GeoGebra dynamic geometry software. Students can think critically, creatively and innovatively to solve non-routine problems, an ability much needed for 21st century learning and constitute an important ability that could assist students' development in other skills (NEA, 2010; Saavedra & Opfer, 2012; MOE, 2013b; MOE, 2017).

2. Analysing

The 21st century learning in education covers analysing, evaluating and sharing information that focusses on reasoning skills (NEA, 2010; Saavedra & Opfer, 2012; MOE, 2017). Students need to possess the ability to convey or express their ideas clearly through presentations or through their products. This study shows that students' works, which they had constructed when using the GeoGebra dynamic geometry software encompasses students' knowledge towards the problem that they are solving, mathematics facts and theorems that are related, application, analysing of information, evaluating and identifying validity of information, and subsequently creating graphic displays that show problem solving and construction of newly learned concepts. The findings in this study is in line with the findings of Jarvis, Hohenwarter and Lavicza (2011) who state that using GeoGebra dynamic geometry software enables students to construct new knowledge and understanding of mathematical concepts as they interact among themselves within the learning environment. Such is also the case with the findings of Wumig (2009) as well as Iranzo dan Fortuny (2011), whereby students can analyse, reason and form relationships between mathematical concepts and their everyday live experiences through the use of GeoGebra dynamic geometry software.

3. Evaluating

In 21st century education, evaluating activities involve students' learning through disciplines which necessitates learning both the knowledge of the discipline and the skills related with the production of knowledge within the discipline. In confronting problems, students should able to define the types of problems, the methods it uses to addresses the problems and the result achieved. The students should able to evaluate against the mathematical dicipline efficiently towards solving the problems and indicate flexibility and willingness to face these challenges. They, at the same time, should be flexible and willing to create new knowledge as well as thinking critically to the significance of the mathematical reasoning towards the development of 21st century skills and knowledge (NEA, 2010; Saavedra & Opfer, 2012; MOE, 2017). The findings in this study show that the process of teaching and learning of Shape and Space using GeoGebra dynamic geometry software could provide opportunities and space for students to discuss and generate new ideas to construct meaningful graphics when solving the given problems. The discussion on using appropriate apparatus or resources to sketch the correct mathematics concepts allows the students to think critically and creatively, probe their thinking and suggest fruitful ideas as well as make clear and accurate presentations and explanations as mentioned by Wurnig (2009), Iranzo and Fortuny (2011) and Jarvis, Hohenwarter and Lovicza (2011).

4. Creating and Constructing Ideas

Creative thinking involves thinking out of the box which is being emphasize in 21st century learning. It encompasses changing of ideas and inquiry learning towards innovative level. Creativity is a natural human characteristic and it can gradually lessen if it is restrained by teachers who preferred a more controlled teaching situations (Saavedra & Opfer, 2012; MOE, 2014; MOE, 2017). This study reveals that teaching and learning using GeoGebra dynamic geometry software as a supporting technology resource enables students to independently use the equipments within the dynamic software which is interactive to assist them in findings connections between the mathematics concepts that they learn. Students were thinking critically and creatively to construct graphics that aided in solving the problems. The graphics created indicate the presence of students' critical and creative thinking that depicts the problem situations, which ultimately assisted them in arriving at the solutions to the problems. The view that the use of GeoGebra dynamic geometry software can stimulate critical thinking, creativity and innovative skills among students were also indicated by students in the case study performed by Iranzo dan Fortuny (2011). The students in their study were at different levels of competence in geometry learning but were able to use the dynamic software to develop creative and innovative geometrical thinking. Interestingly, GeoGebra had also supported the students' visualization skills and algebra learning.

CONCLUSION

This study provides evidence of the effectiveness of using GeoGebra dynamic geometry software in the learning of Shape and Space among Form Two students. The findings of this study imply that mathematics teachers may resort to alternative approach to teach Shape and Space by integrating ICT in the teaching and learning activities. The use of GeoGebra dynamic geometry software has the potential to improve and enhance students' knowledge and skills – critical, creative and innovative thinking – towards supporting problem-based learning as an approach in 21st century learning. More Mathematics teachers in Malaysia's secondary schools should be exposed to GeoGebra dynamic geometry software because it is a type of technology software with geometry system that is interactive and very efficient. Therefore, the Curriculum Development Division, or other relevant parties, should provide opportunities for Mathematics teachers to attend trainings on the integration of ICT by using dynamic mathematical interactive software in teaching and learning to support 21st century learning of mathematics in schools.

Nevertheless, we do note the need to be cautious in stating the aforementioned conclusion with regards to the effectiveness of using the dynamic software within this study and the implications drawn from the limitations. Since the participants were only Form Two students from one school, hence, we recommend this study to be extended by involving participants from different schools. In doing so, the different schools students' performance after being exposed to GeoGebra dynamic geometry software can be compared to provide more conclusive findings. The other limitation pertains to the sort of interventions that were exposed to the experimental groups. Both the experimental groups in this study underwent teaching and learning sessions based on the validated guideline book developed by the researchers. We are of the opinion that the use of other validated guideline books or modules, that are developed or written by other researchers, on learning of Shape and Space using GeoGebra dynamic geometry software by a number of experimental groups during the intervention phase could portray a more convincing scenario pertaining to the effect of GeoGebra dynamic geometry software on Form Two students' learning of geometry. Nonetheless, we anticipate that the findings within this study and the validate guideline book that we had developed would contribute in one way or another towards making mathematics teaching and learning in schools become more interesting, appealing and meaningful to the students. Dynamic interactive software, as shown by the findings in this study, should be used in mathematics classrooms as often as possible, especially with the advancement of technology usage in schools to support and endorse the transformation of education and 21st century learning.

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