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Application of GeoGebra in Model Based Learning and Students' Academic Performance in Solid Geometry

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Abstract: ***Mathematics Education as a transdisciplinary course of study has been reimaged in foresight of the fifth industrial revolution, driven by digitization, digitalization, and digital transformations. This study investigated the effects of GeoGebra-Supported Model Based Learning (GSMBL) on students' academic performance in Solid Geometry in Uyo Metropolis of Akwa Ibom State, Nigeria. Quasi-experimental; a pretest-posttest non-equivalent control groups design was adopted for the study. Using purposive-random sampling approach, two intact classes were derived from two schools. The instrument for data collection; Solid Geometry Performance Test (SGEPT), trial-tested on a group of students had a reliability index of 0.87. Treatments were given to the two groups via lessons on Solid Geometry, and analysis of covariance (ANCOVA) was used to analyse and interprets datasets. The results of the study shown that, students exposed to GeoGebra Supported Model Based Learning performed significantly higher than students taught Solid Geometry using Engagement Learning Strategy. This was attributed to the technological affordance inherent in GeoGebra, being a Dynamic Geometry System. Similarly, gender had no significant effect on students' academic performance when taught the concept of Solid Geometry using the two teaching strategies. This was attributed to active involvement, equity, and inclusiveness of all learners during the learning processes. Male and female showed equal cognitive abilities, adaptation and accommodation in a dynamic-interactive learning environment. It was recommended that Mathematics teachers should diversify instructional approaches through utilization of digital tools. Stakeholders and government should provide Mathematics Laboratory with state-of-the-art facilities to promote the teaching and learning of Mathematics in Secondary schools.***

Keywords: GeoGebra, Model-Based Learning, Engagement Learning Strategy (ELS), Solid Geometry, Academic Performance, Mathematics

1. Background of the Study

Modern Education system is dynamic, which depicts constant changes in the nature and approaches to the teaching and learning of Mathematics. There are robust emphasize on the use of digital technologies to facilitate the teaching and learning of Mathematics (Charles-Ogan, 2016). Digital tools used for learning of mathematics include computer applications; Dynamic Geometry Systems (DGS), online and blended learning tools (Awodey, et al, 2014; Umoh & Akpan, 2014). An example of a Dynamic Geometry System is GeoGebra used for the teaching and learning of mathematics. GeoGebra is an interactive and user friendly Mathematics learning environment invented in 2001 by Marcus Hohenwarter (Bu & Schoen, 2011). GeoGebra is freely available for usage as an open source to the entire research community, individual's reflection and web-based social interaction. GeoGebra software takes advantage of technological affordance to create a community, actively involved in addressing traditional Mathematical problems in the classroom, while fostering the development of new pedagogical practices and research in Mathematics Education (Bu & Schoen, 2011). Its uses graphical utility packages with different geometric dimensions, to simulate and model real-life phenomena in Mathematics (Hall & Lingefjiard, 2017).

Notably, modelling of Mathematical objects as embedded in GeoGebra exemplifies a model-based learning strategy, and integration of technology in the teaching of Mathematics. The Mathematical modelling processes create a complex structural relationship between three entities of different epistemological nature: the situation that is to be modelled, mathematical system, and technological components (Stillman, et al.2013; Greefrath & Vorholter, 2016). The implementation of model based learning with digital tools in Mathematics classroom requires a pedagogical modelling cycle. A modelling cycle is used to help students to understanding the modelling processes involve in solving the problem, and to promote modelling competence beyond the classroom (Lesh, et al.2013; Vorhölter, et al.2019). Greefrath, and Vorholter (2016) modelling cycle adopted for this study is represented diagrammatically as follows.

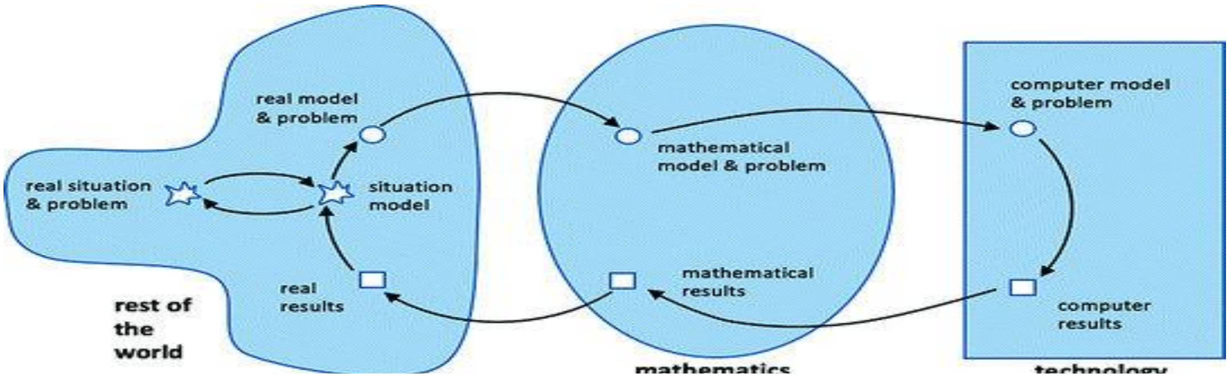

Figure 1: Mathematical modelling cycle with technology component (Greefrath & Vorholter, 2016)

Considering figure 1, the modeller constructs a situation model; an issue of interest or a real problem that requires solutions. Parameters and variables of interest are defined to simplify the situation-real model. Secondly, Mathematics is used to transform the rest of the world into a mathematical model which consists of formulating equations using the variables. This involves manipulations of the variables, scaling, classifications of equations and derivation of formulas. Thirdly, the technological component is introduced to augment and enable speedy solution as well as fostering learners' manipulative skills, metacognitive development and twenty-first century skills. For instance, situation and mathematical problems can be transformed to a geometric model or it can be experimented by means of dynamic geometry software such as GeoGebra. Computer results; simulations, animations and graphics obtained are being interpreted using Mathematical language, logic, symbols, notations and numeric. Similarly, the results can be extended to the real-life interpretations for predictive and decision making purposes. A validation of the results, ensures its appropriateness or necessity to go round the loops again, in order to account for more factors or new variables (Gilbert, & Justi, 2016).

Our natural environment has numerous geometric patterns and arrangements. Solid geometry entails the study and measurement of the properties of one, two, three dimensional shapes and more (Aart, 2008). Three dimensional shapes include cube, prism, sphere, hemisphere, cylinder, volume, cone, pyramid, and cuboid. This makes the teaching and learning of solid geometry an important theme in senior secondary school Mathematics curriculum as stipulated by Nigeria Educational Research and Development Council (NERDC, 2012). Thus, it's imperative to investigate student academic performance while learning the concepts of Solid Geometry via technological supportive tools; GeoGebra, in a model-based learning environment.

2. Statement of the Problem

Mathematics as a utility subject in secondary schools establishes its efficacy in classroom learning and its functions in real-life among members of the larger society. The concerted effort of Mathematics Educators and stakeholders to achieving the national Mathematics objectives as stipulated by NERDC (2012) could be hindered through ineffective integration of technology to pedagogical content knowledge. These could be attributed to incompetent human resources deployed to teaching and learning of the subject matter, and lack of teachers' technological pedagogical content knowledge (TPCK). Consequently, these affect the implementation of the subject matter in schools, and leading to poor academic performance of students in Mathematics and related subjects. These raise pertinent exploratory questions; how can teachers augment and facilitate the teaching and learning of Mathematics using 21st century technology? These could give the learners opportunities to manipulate the learning environment and foster transfer of learning as well as solving of real life problem. Hence, this study seeks to determine the effectiveness of GeoGebra Supported Model-Based Learning (GSMBL) and Engagement Learning Strategy (ELS) on student academic performance in the concept solid geometry.

3. Aims and Objectives of the Study

This study seeks to investigate the effect of two instructional strategies; GeoGebra Supported Model-Based Learning (GSMBL), and Engagement Learning Strategy on students' academic performance in solid geometry in Uyo metropolis, Akwa Ibom State. The specific objectives of the study include the following;

1) To determine the effect of GeoGebra Supported Model-Based Learning (GSMBL), and Engagement Learning Strategy (ELS) on academic performance of students' in Solid Geometry.
2) To investigate the effect of gender on students' academic performance in solid geometry when taught using GeoGebra Supported Model-Based Learning (GSMBL) and Engagement Learning Strategy (ELS).

4. Research Questions

The research questions derived to guide the study include the following;

1) What is the effect of GeoGebra Supported Model-Based Learning (GSMBL), and Engagement Learning Strategy (ELS) on students' mean performance scores in Solid Geometry?
2) What is the effect of gender on students' academic performance in solid geometry when taught using GeoGebra Supported Model-Based Learning (GSMBL) and Engagement Learning Strategy (ELS).

5. Research Hypotheses

H_{01}: There is no significant difference in the mean performance scores of students taught solid geometry using GeoGebra Supported Model-Based Learning (GSMBL), and Engagement Learning Strategy (ELS), respectively.

H_{02}: Gender has no significant difference on students' academic performance in solid geometry when taught using GeoGebra Supported Model-Based Learning (GSMBL) and Engagement Learning Strategy (ELS), respectively.

6. Significance of the Study

This study could expose Mathematics teachers on how to make use of innovative and digital resource such as GeoGebra to foster effective and efficient teaching of solid geometry. Also, learners will experience and practice mathematical activities that promote the twenty first century skills, such as creativity, critical thinking, collaborative skills and transfer of learning.

7. Research Design

This study adopts quasi-experimental design; a non-equivalent control group design. This entails a non-complete randomization of the study participants (students) to the experimental and control groups. The experimental groups were exposed to the teaching of Solid Geometry using GeoGebra Supported Model Based Learning (GSMBL), while the control groups were taught Solid Geometry using Engagement Learning Strategy.

8. Population for the Study

The population of the study consist of four thousand, nine hundred and thirty seven (4, 937) senior secondary II (SSII) students of fourteen (14) public secondary Senior schools in Uyo, Local Government, Akwa Ibom State (State Secondary Education Board [SSEB], 2021).

9. Sample and Sampling Techniques

A total sample size of one hundred and thirty eight (138) students was selected from two (2) public secondary schools using purposive-random sampling technique. The sampling was a random selection of two intact classes each from the two schools. The two intact classes represented experimental and control group respectively. These schools have qualified mathematics, Basic Technology, and computer Education teachers. The table below is the sampling frame for the study.

Table 1: Sampling frame

	Groups	Male	Female	Total
1	GeoGebra Supported Model-Based Learning (GSMBL)	23	41	64
2	Engagement Learning Strategy (ELS)	38	36	74
	Total	61	77	138

10. Method of Data Collection

The researcher seeks permission from the principal of the schools selected for the study, which was duly granted. On one hand, a class of students selected for experimental treatment was taught the concept of Solid Geometry using GeoGebra Supported Model Based Learning (GSMBL). On the other hand, the class of students selected for the control group was taught using Engagement Learning Strategy (ELS). The instrument of data collection was "Solid Geometry Performance Test (SGEPT)" consisting of thirty multiple choices questions, with options (A to D) developed from Senior School Certificate Examination (SSCE) past questions. Using the instrument of the study; SGEPT, a pre-test was given to the students participating in the study, and post-test was given to the two groups after interventions, respectively

11. Validation of the instruments

The instrument for data collection; Solid Geometry Performance Test (SGEPT) was subjected to face and content validities. The validation was performed by two research experts in Test and Measurement and a Mathematics Education lecturer from the Department of Science Education of the University of Uyo. Recommendations and comments made by the validators were effected accordingly.

12. Reliability of the instruments

The instruments of this study, namely Solid Geometry Performance Test (SGEPT) was trial tested on a group of ninety six (96) students, having equivalent characteristics as the study sample and retested after three weeks on the same set of students. A Pearson Product Moment Correlation (PPMC) analysis and corrected using Spearman-Brown formula which yielded a reliability coefficient of 0.87.

13. Method of data analyses

Dataset obtained from the study after treatments were analysed using descriptive and inferential test statistic. The Means and standard deviations obtained for the experimental and control groups were used to answer the research questions, while Analysis of Covariance (ANCOVA) was used to test the research hypotheses at 0.05 level of significance.

Presentation of Results

The results and discussions of the study are presented in this section

Table 2: Descriptive Statistic of Students academic Performance using the three strategies

strategies		pre-test		post-test		Mean Gain
	N	$\bar{X}$	*SD*	$\bar{X}$	*SD*	
GeoGebra-Supported Model Based Strategy	64	15.33	3.70	22.78	3.92	7.45
Engagement Learning Strategy	74	17.24	2.81	20.86	4.31	3.62

Table 2 showed the pretest (*M* = 15.33, *SD* = 3.70) and posttest (*M* = 22.78, *SD* = 3.92) scores of students taught solid geometry using GeoGebra Supported Model-Based Learning. Also, it indicates the pretest (M = 17.24, SD = 2.81) and posttest (M = 20.86, SD = 4.31) scores of students taught Solid Geometry using Engagement Learning Strategy.

The mean gain score for students taught Solid Geometry using GeoGebra-Supported Model Based Learning was 7.45, while the mean gain score of students taught Solid Geometry using Engagement Learning Strategy was 3.62.

Table 3: Descriptive statistic by gender of student performance

Strategies			Pre-Test		Post-Test		mean gain
	gender	*N*	$\bar{X}$	*S. D*	$\bar{X}$	*S. D*	
GeoGebra-Supported Model Based Learning	male	23	15.52	4.07	22.55	3.89	7.02
	female	41	15.21	3.53	22.93	3.98	7.72
Engagement Learning Strategy	male	38	18.5	2.63	20.63	4.37	2.13
	female	36	15.92	2.38	21.11	4.29	5.91

Table 3 showed the pretest mean and standard deviation scores of male (*M* = 15.52, *SD* = 4.07) and female (*M* = 15.21, *SD* = 3.53) students taught using GeoGebra Supported Model-Based Learning. In the same vein, it indicates post-test mean and standard deviation scores of male (*M* = 22.55, *SD* = 3.98) and females students taught using GeoGebra Supported Model-Based Learning. The mean gain scores of male and female students taught using GeoGebra supported Model-Based Learning were 7.02 and 7.72 respectively.

Similarly, the table shown the pre-test mean and standard deviation scores of male (*M* = 18.50, *SD* = 2.63) and female (*M* = 15.92, *SD* = 2.38) students taught Solid Geometry using Engagement Learning Strategy. Its gives the post-test mean and standard deviation scores of male (*M* = 20.63, *SD* = 4.37) and female (*M* = 21.11, *SD* = 4.29) students taught Solid Geometry using Engagement Learning Strategy. The mean gain scores of male and female students taught Solid Geometry using Engagement Learning Strategy were 2.13 and 5.91 respectively.

Table 4: ANCOVA of students' academic performance by teaching strategies

Source	Type III Sum of Squares	DF	Mean Square	F	Sig.
Corrected Model	149.019[a]	2	74.509	4.368	.015
Intercept	2043.073	1	2043.073	119.784	.000
Pretest	22.982	1	22.982	1.347	.248
Strategies	147.013	1	147.013	8.619	.004
Error	2302.604	135	17.056		
Total	67756.000	138			
Corrected Total	2451.623	137			

Table 4 shown that there is significant difference in the mean performance scores of students taught Solid Geometry using GeoGebra Supported Model Based Learning and Engagement Learning Strategy [F (1, 135) = 8.619, p = 0.04], while the pretest was used as the covariate to reduce the confounding effects on students' academic performance. Hence, the null hypothesis was rejected.

Table 5: ANCOVA Students mean performance based on gender

Source	Type III Sum of Squares	DF	Mean Square	F	Sig.
Corrected Model	165.15[a]	4	41.289	2.402	.053
Intercept	1770.51	1	1770.51	102.99	.000
Pretest	32.45	1	32.45	1.89	.172
Strategies	138.73	1	138.73	8.07	.005
Gender	13.95	1	13.95	.81	.369
Strategies * Gender	1.49	1	1.49	.09	.769
Error	2286.47	133	17.19		
Total	67756.00	138			
Corrected Total	2451.62	137			

The table 5 shown that gender has no significant effects on student mean performance scores when they are taught using the two different teaching strategies [F (1, 133) =.81, p =.369], while pretest was use as a covariate to reduce the effects of confounding variables on the dependent variable. Hence, the null hypothesis was accepted.

14. Discussion of Results

Table 2 shown that students taught Solid Geometry using GeoGebra Supported Model-Based Learning had the higher academic performance mean scores when compared to those taught the same concepts using Engagement Learning Strategy. It was affirmed in table 4 that the differences in students' academic performance were statistically significant among the two teaching strategies. This effect could be attributed to the manipulative and visualization characteristics of the integration of GeoGebra software to model based teaching strategy. Mamman and Isa (2019) reported the effectiveness of GeoGebra to the teaching and learning of Mathematics. They concluded that GeoGebra enhances students' conceptual and procedural knowledge in

Mathematics. Ajaegba and Ekwueme (2019) found out that GeoGebra software incorporated in Mathematics classroom reinforces students' interest and motivation as they learn the concept of plane geometry. Animation and simulation facilities are embedded in GeoGebra software, which could be the reasons for its efficiency to foster students' academic performance in the concept. Empirical study conducted by Williams, Charles-Ogan and Adesope (2017) on GeoGebra interactive software opted that Geogebra application software increases students' interest and performance in Mathematics. In line with this study is the results of Oli and George (2020), they reported that GeoGebra software improves students' performance in trigonometry with dyscalculia impairment. This dynamic geometric learning tool inculcates problems solving skills as students elaboration, practice the basic operations of mathematics though drill a practice modes.

Furthermore, table 3 indicated that female students had higher mean performance scores compared to male when taught the concept of Solid Geometry using GeoGebra Supported Model-Based Learning Strategies. Also, female students mean performance scores was higher than male students scores when taught Solid Geometry using Engagement learning strategy. However, table 5 shown that there was no significant difference in mean performance scores of students by gender as they were taught the same concepts using the two different teaching strategies. This entails that gender could not predicts students' academic performance in Mathematics, and it could be attributed to the gender equity guaranteed by technology supported model-based learning in Mathematics classroom. According to Gamage and Charles-Ogan (2019) in a study on GeoGebra software and students' performance in teaching and learning of circle geometry. They found out that gender effects were not significant, while students were taught the concepts of Circle Geometry using GeoGebra. This could be attributed to the inclusive nature of GeoGebra software; provisions of optimal development and participation all individuals through interactivity. Thus, male and female students' cognitive architecture develops in similar patterns and its being shaped though effective teaching strategy such as the use of GeoGebra. Consequently, male and female students have equal cognitive ability levels to study the subject matter and achieve better results in any transitional examinations such as Senior School Certificate Examinations.

15. Conclusion

All in all, the study envisaged that using GeoGebra software to support Model Based learning and teaching of Mathematics enhances students' academic performance in the concept of Solid Geometry. This effect was attributed to the dynamic, interactive and visualization features embedded in GeoGebra software application. In the same vein, gender couldn't predict students' academic performance in Mathematics. This was attributed to technology affordance and inclusiveness of GeoGebra software during the teaching and learning of solid geometry.

16. Recommendations

The following recommendations were made;

1) Mathematics teachers and instructional technologist should diversify instructional strategies and methods of teaching the subject through the use of Geometry Dynamic System; GeoGebra Application Software.
2) Education stakeholders should provide state-of-the-art Mathematics Laboratory to facilitate the use of digitals for teaching and learning of Mathematics in secondary schools.

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