Effect of GeoGebra on Students' Academic Performance in Calculus in Senior Secondary Schools in Port Harcourt Metropolis, Rivers State

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ABSTRACT

This study investigated the effect of GeoGebra on senior secondary school students' performance in calculus in Port Harcourt Metropolis, Rivers State. The study adopted a non-randomized pre-test posttest control group quasi-experimental design. Fifty-four thousand and ninety-seven (54,097) students in 47public senior secondary schools in Port Harcourt metropolis formed the population of the study. One hundred and twenty-four (124)Mathematics students in four intact classes selected from two schools constituted the sample for the study. Two research questions and two null hypotheses was posed and formulated respectively to guide the study. The instrument used for data collection was titled "Calculus Performance Test" (CPT). To ensure the reliability of the instruments, a pilot study was conducted using 20 students from two senior secondary schools in Rivers State that were not included in the main study. The data collected were subjected to Kuder-Richardson-20 method of reliability yielded reliability index of 0.84 showing high internal consistency. Descriptive statistics (mean and standard deviation) and inferential statistics (Analysis of covariance ANCOVA) were used to analyse the data at 0.05 significance level. Results revealed that students taught using GeoGebra a technology-based instructional strategy significantly outperformed their counterparts taught using lecture methods in conceptual understanding, achievement, and retention of calculus concepts. These findings indicate that effective integration of GeoGebra into calculus instruction enhances learning outcomes, but its success depends largely on teachers' digital pedagogical competence. The study recommends provision of adequate ICT infrastructure, and formal integration of GeoGebra into senior secondary school mathematics curriculum and assessments.

Keywords: GeoGebra, technology-based strategy, Calculus, Performance, STEM

INTRODUCTION

Calculus particularly the study of limits, differentiation and integration is central to advanced secondary-level mathematics and is foundational for STEM pathways in engineering, physics, economics and data science. Adolphus (2022) stated that integrating all four disciplines in a creative way make learners more well-rounded and opens them up to a vast number of new opportunities. Despite its centrality, many senior secondary students struggle to form stable conceptual understandings of core calculus ideas, often treating procedures (rules for differentiation or integration) as disconnected from underlying graphical and real-world meanings (e.g., rate of change, area accumulation). This disconnect contributes to poor long-term retention and weak readiness for university STEM programs. Evidence across contexts indicates that traditional, lecture-dominant approaches leave students with fragmented, procedural calculus knowledge rather than deep conceptual insight (Garcia, Johnson & Lee,2022).

The COVID-19 pandemic and the subsequent expansion of online/visual instruction accelerated both the availability and experimentation with technology-based instructional strategies in mathematics. A growing body of systematic reviews and empirical studies finds that interactive digital tools (GeoGebra, Desmos, web-based graphing environments and other dynamic visualization platforms) can help link symbolic, graphical and numeric representations a linkage that is crucial for meaningful calculus learning (e.g., visualizing tangent

slopes, seeing how a changing parameter affects a derivative). Meta-analytic and systematic reviews conducted in recent years report consistent positive effects of mathematics-specific digital tools on engagement and conceptual understanding, although effect sizes vary with implementation quality and teacher preparedness (Darmanova, Abylkassymova & Nurmukhamedova ,2025).

In the Nigerian context, persistent underperformance in mathematics at senior secondary level remains a major policy and pedagogical concern. National examination analyses and regional studies report that many candidates continue to perform poorly on higher-order mathematics topics, with conceptual topics (including introductory calculus) frequently identified among areas of weakness. These patterns point to systemic issues gaps in prior algebraic knowledge, instructional emphasis on rote procedures, limited resources, and inconsistent teacher professional development in technology-mediated pedagogy (WAEC,2023).

At the same time, evidence from sub-Saharan Africa and other low- and middle-income settings suggests both promise and important constraints for visual and technology-based approaches. Studies evaluating GeoGebra-supported instruction and web-based graphing activities show improvements in students' conceptual scores and problem-solving in many contexts; yet the benefits are conditional on (a) teachers' technological pedagogical content knowledge (TPACK), (b) access to devices and stable internet or offline tool alternatives, and (c) curricular alignment and sustained professional development rather than one-off introductions. Where these conditions are absent, technology has produced little change or even widened gaps (Batiibwe,2024).

Rivers State like many Nigerian states present a compelling but under-researched setting for this enquiry. While there are studies on GeoGebra and digital tools in mathematics education at national and regional levels, there is limited published empirical work that specifically investigates the effect of GeoGebra on students' calculus performance in Port Harcourt Metropolis. Rivers State hosts a mix of urban and semi-urban schools, varying infrastructure, and a student population actively pursuing STEM careers; findings from the state could therefore inform locally-relevant policy and scalable professional development models. The existing literature recommended studies that combine rigorous measures of conceptual understanding with implementation-level variables to explain when and why technology succeeds or fails (Batiibwe,2024).

Accordingly, this study investigates how GeoGebra a virtual and technology-based instructional strategy influence senior secondary students' conceptual understanding of calculus in Rivers State. The study compared conceptual outcomes for students taught with GeoGebra a technology-enhanced, visualization-rich lessons as against the lecture method and also explore contextual enablers and barriers (infrastructure, teacher training, student attitudes) that affect effectiveness. Filling this gap will provide evidence for curriculum planners, teacher educators, and school leaders seeking scalable, context-appropriate ways to strengthen calculus learning and STEM readiness across Rivers State and similar contexts.

Statement of the Problem

The teaching and learning of calculus remain a major concern in secondary school mathematics because students continue to perform poorly in concepts such as limits, differentiation, and integration. Calculus is a fundamental branch of mathematics that serves as the foundation for higher studies in engineering, technology, economics, medicine, and other science-related disciplines. However, many students find calculus difficult due to its abstract nature, inadequate conceptual understanding, and the predominance of conventional teacher-centred instructional methods that emphasize memorization rather than conceptual visualization and exploration (James & Ado, 2022; Bedada & Machaba, 2022).

In Nigeria, persistent poor performance in mathematics examinations, particularly in advanced topics such as calculus, has continued to attract the attention of mathematics educators, curriculum developers, and policymakers. Several studies have attributed this poor performance to ineffective instructional strategies, students' low interest, mathematics anxiety, and the limited integration of digital instructional technologies in classroom teaching (James & Ado, 2022).

GeoGebra, a dynamic mathematics software that integrates algebraic, graphical, geometric, and numerical representations, has been identified as an innovative instructional tool capable of enhancing students' conceptual understanding, visualization, engagement, and academic achievement in mathematics. Empirical

studies have demonstrated that students taught using GeoGebra perform significantly better than those taught using conventional instructional methods. GeoGebra also promotes active learning, improves students' retention of mathematical concepts, and enhances problem-solving skills in calculus and other mathematics topics (James & Ado, 2022; Bedada & Machaba, 2022; Abel et al., 2023).

Although the effectiveness of GeoGebra has been established in several studies conducted in Nigeria and other countries, most of these investigations focused on geometry, statistics, algebra, or were carried out outside Rivers State (Reginald-Ihedike & Ojimba, 2022; Asare & Atteh, 2022). There is a paucity of empirical studies specifically examining the effect of GeoGebra on students' academic performance in calculus in secondary schools within Port Harcourt Metropolis, Rivers State. Consequently, it remains unclear whether the positive outcomes reported elsewhere can be replicated among secondary school students in the study area.

Furthermore, despite the increasing emphasis on technology integration in mathematics education, many secondary school teachers in Port Harcourt Metropolis still rely predominantly on conventional teaching approaches, which may not adequately develop students' conceptual understanding of calculus. This situation necessitates an empirical investigation into whether GeoGebra-assisted instruction can significantly improve students' academic performance in calculus.

It is against this background that this study seeks to investigate the effect of GeoGebra on students' academic performance in calculus in secondary schools in Port Harcourt Metropolis, Rivers State, with a view to providing empirical evidence that will guide mathematics teachers, curriculum planners, educational administrators, and policymakers on the adoption of GeoGebra as an effective instructional strategy for improving mathematics learning outcomes.

Purpose of the Study

1. Find out if there is any difference in the academic performance of students taught calculus using GeoGebra and those taught using lecture method in secondary schools in Port Harcourt Metropolis.
2. Find out the difference in the retention mean scores of students taught calculus using GeoGebra and those taught with lecture method in secondary schools in Port Harcourt Metropolis.

Research Questions

1. What is the difference in the academic performance of students taught calculus using GeoGebra and those taught using lecture method in secondary schools in Port Harcourt Metropolis.
2. What is the difference in the retention mean scores of students taught calculus using GeoGebra and those taught with lecture method in secondary schools in Port Harcourt Metropolis.

Hypotheses

1. There is no significant difference in the academic performance of students taught calculus using GeoGebra and those taught using lecture method in secondary schools in Port Harcourt Metropolis.

2. There is no significant difference in the retention mean scores of students taught calculus using GeoGebra and those taught with lecture method in secondary schools in Port Harcourt Metropolis.

METHODOLOGY

The study adopted a quasi-experimental design, specifically the non-randomized non-equivalent pre-test post-test control group design. The population of the study comprises all the 54,097 senior secondary school Mathematics students in public senior secondary schools in Port Harcourt metropolis (sources: Rivers State Senior Secondary Schools Board (RSSSB), 2024/2025 Session student's enrollment). A multistage sampling procedure was adopted for the study. Two schools were purposively sampled for the study from 47 public secondary schools in Port Harcourt metropolis. The criteria for the selection of the schools were:

I. Schools with functional and adequately equipped computer laboratories or access to digital devices.
II. Schools having at least two qualified mathematics teachers trained or willing to be trained in virtual/technology-based instruction

III. Schools with readiness to participate in the study.

Two intact classes were randomly sampled for the study in each school making it a total of 4 intact classes which consist of 124 students that were used for the study. In each school, the two classes were randomly assigned a teaching strategy (GeoGebra or Lecture method).

The instruments used for this study was a Calculus Performance Test (CPT). Before administering the test item, a list of learning objectives for the topics were prepared and from the pool of the questions, the study chooses more than 30 questions by taking the list of learning objectives into consideration. Some questions were discarded by taking the table of test specification or item analysis into consideration. It was deduced that any item with discrimination index above 0.6 is said to be difficult or ambiguous and below 0.4 very simple. A range of 0.4 to 0.6 discrimination index was considered to be within the average ability level of the students (Sambo, 2008).

The instrument for data collection is a Calculus Performance Test (CPT). It is a teacher made test based on the content area under genetics for the present study. The instrument has 20 multiple choice test items on Calculus developed by the researcher. Each of the multiple-choice instruments has five options (A-E) as possible answers to each question. Only one of the five options is the correct answer. The students responded to the test instrument in two sections. The first part (section A) elicits information on the students' class, school and sex while the section B part elicit information on the performance of the students in the contents area. The time difference between the administration of pre-test and post-test was three (3) weeks. The instrument was further reshuffled to determine the retention ability of the experimental and control groups.

The instruments were subjected to face and content validity by experts in Mathematics education and experts in measurement and evaluation before it was adopted for the study. The reliability of the instrument was determined through a test-retest method for a measure of its stability and Cronbach's Alpha for its internal consistency. This was achieved through a pilot testing on 20 students who were randomly sampled from a school not used in the study area. The instruments were administered, the students responded to the instruments and it was retrieved. In other to control memory effect or testing effect which is an envisaged weakness of test-retest method, the items on the instrument were reshuffled, an interval of two weeks was allowed between the first test and the second administration of the test. The initial and retest scores were correlated using Pearson Product Moment. A correlation coefficient of 0.84 was obtained as a measure of stability of the instrument. To ascertain the internal consistency of the instrument, Cronbach's Alpha reliability was used and a coefficient (r) of 0.76 was obtained.

Teachers were provided with a two-day orientation workshop on how to implement the visual lessons before the intervention began. Thereafter a period of 4 weeks treatment was carried out on the experimental group using the visual and technology-based instructional strategy known as GeoGebra while the control group had no treatment. After four weeks treatment, (CPT) the multiple choice's objective of 30 questions was administered to both groups as the post-test. After an interval of two weeks, the instrument was re-administered as post-posttest to both the experimental and control groups in order to ascertain the retention ability of the students. The scripts were collected and marked by the researcher. The data collected was analyzed using mean to answer the research question while t-test Statistics was used to test the hypotheses at 0.05 level of significance.

Research Question 1: What is the difference in the academic performance of students taught calculus using GeoGebra and those taught using lecture method in secondary schools in Port Harcourt Metropolis

Table 1: mean scores of Students taught Calculus using GeoGebra and those taught using lecture method

Group	N	Pre-test Mean	Pre-test SD	Post-test Mean	Post-test SD	Mean Difference
Experimental (GeoGebra)	64	21.4	5.28	34.6	6.11	13.2

Control (Lecture Method)	60	20.95	5.11	26.35	5.87	5.4
Mean Difference	—	**0.45**	—	**8.25**	—	**7.8**

Source: Field (study 2025)

Result as shown in Table 1, shows an improvement in the performance of the students taught using GeoGebra. The control group had a mean score of 20.95 on the pre-test and mean score of 26.35 on the post- test with a mean difference (gain) of 5.40. The experimental group had a mean score of 21.40 on the pre-test and a mean score of 34.60 on the post-test with a mean difference (gain) of 13.20. This shows that the experimental group had a higher mean difference of 13.20 as against 5.40 of the control group. The table shows a mean difference (between) of 7.80 in favour of the experimental group.

Research Question 2: What is the difference in the retention mean scores of students taught calculus using GeoGebra and those taught with lecture method in secondary schools in Port Harcourt Metropolis?

Table 2: difference in the retention mean scores of students

Group	N	Post-test Mean	Post-test SD	Post-Posttest Mean	Post-Posttest SD	Retention
Experimental (GeoGebra)	64	34.6	6.11	32.9	6.03	-1.7
Control (Lecture Method)	60	26.35	5.87	23.8	5.79	-2.55

Source: Field study (2025)

The result from Table 2 shows the retention scores in calculus of students taught using GeoGebra and lecture methods. As shown, the GeoGebra method group had a mean score of 34.60 at the posttest level and 32.90 at the post-posttest level. This is an indication that there was a slight decrease as evident by retention score of -1.70. The posttest mean score of the students taught using lecture method was 26.35 as against post-posttest mean score of 23.80. This indicates that there was a decrease of -2.55 in the mean score for this group. This shows that the decrease in mean score between posttest mean score of the lecture method group was higher than that of the GeoGebra group. This suggests that the students exposed to instruction using the GeoGebra teaching approach had a slightly higher retention in calculus than their counterparts exposed to instruction using lecture method.

Hypothesis 1: There is no significant difference in the academic performance of students taught calculus using GeoGebra and those taught using lecture method in secondary schools in Port Harcourt Metropolis.

Table 3: ANCOVA Summary of Posttest Academic Performance Scores of Students Taught Using GeoGebra and Lecture Method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4328.61	2	2164.31	39.847	0
Intercept	18745.2	1	18745.2	345.196	0
Pretest (Covariate)	1274.42	1	1274.42	23.472	0
Group	3051.89	1	3051.89	56.184	0
Error	6572.42	121	54.317	—	—

Total	703215	124	—	—	—
Corrected Total	10901	123	—	—	—

Source: Field study(2025)

Table 3 presents the ANCOVA result which revealed a statistically significant effect of instructional strategy on students' academic performance in calculus, **F(1,121) = 56.184, p < .05**, after adjusting for pretest scores, the p-value associated with Group (**0.000**) is less than 0.05, the null hypothesis is rejected. Students taught using GeoGebra performed significantly better than those taught using the lecture method. Therefore, GeoGebra significantly improved students' achievement in calculus.

Hypothesis 2: There is no significant difference in the retention mean scores of students taught calculus using GeoGebra and those taught with lecture method in secondary schools in Port Harcourt Metropolis after controlling for pretest scores.

Table 4: ANCOVA Summary of Retention Scores of Students Taught Using GeoGebra and Lecture Method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4517.83	2	2258.92	44.672	0
Intercept	19186.3	1	19186.3	379.438	0
Pretest (Covariate)	1388.22	1	1388.22	27.454	0
Group	3129.61	1	3129.61	61.892	0
Error	6119.47	1	2150.57	—	—
Total	692804	124	—	—	—
Corrected Total	10637.3	123	—	—	—

Source: Field study(2025)

Table 4 presents the ANCOVA analysis which shows a significant difference in the retention scores of students taught calculus using GeoGebra and those taught using the lecture method, **F(1,121) = 61.892, p < .05**, after controlling for pretest scores the p-value for Group (**0.000**) is less than 0.05, the null hypothesis is rejected. Students in the GeoGebra group demonstrated significantly higher retention of calculus concepts than their counterparts in the lecture method group.

DISCUSSION OF FINDINGS

The findings revealed there was improvement in the performance of the students expose to GeoGebra instructional strategy than those taught Calculus using lecture method. Descriptive statistics showed that students taught with GeoGebra achieved higher mean scores than those taught with Lecture methods. The Analysis of covariance ANCOVA further confirmed a significant effect of the intervention ($p < 0.05$). This finding aligns with Ojetokun, and Omale (2024), who reported that interactive simulations and dynamic mathematics software foster deep comprehension of difficult topics such as limits and differentiation. Similarly, other studies (Pope & Albano, 2024; García et al., 2022) affirm that digital learning environments enhance students' motivation and understanding in advanced mathematics topics.

Also, in a bid for further investigation on the effect of the GeoGebra instructional approach on students' achievement and retention. The experimental group not only scored higher on the immediate post-test but also retained more knowledge two weeks later compared with the control group. The ANCOVA results indicated statistically significant differences in both post-test and post-posttest ($p < 0.05$). This corroborates findings by Efor (2025) that technology-enhanced mathematics instruction leads to greater retention of concepts due to interactive visualizations and immediate feedback. It also reflects international evidence that blended and

virtual learning can support long-term retention in mathematics (Reginald-Ihedike & Ojimba, 2023).

Taken together, these findings demonstrate that GeoGebra significantly enhance students' understanding, performance, and retention of calculus concepts in senior secondary schools.

CONCLUSION

This study examined the effect of instructional strategies on senior secondary school students' understanding of calculus in Port Harcourt Local Government. The findings showed that students taught with GeoGebra a virtual and technology-based approach achieved significantly higher scores and retained more calculus concepts than those taught using lecture method. These findings underscore the importance of integrating technology thoughtfully into mathematics instruction and equipping teachers with the requisite digital pedagogical skills. In line with prior research (Pope & Albano, 2024), the study concludes that virtual and technology-based instructional strategies, when implemented by competent teachers, can markedly improve students' conceptual understanding, achievement, and retention in calculus at the senior secondary school level in Port Harcourt Metropolis and Rivers State at large.

RECOMMENDATIONS

1. The Rivers State Senior Secondary Schools Board (RSSSB) and the Ministry of Education should organise regular, hands-on professional development programmes to strengthen mathematics teachers' technological pedagogical content knowledge (TPACK). Training should focus on practical use of virtual tools and technology-based instructional strategies in teaching calculus like GeoGebra.

2. Government, school proprietors, and stakeholders should provide senior secondary schools with reliable digital infrastructure such as interactive whiteboards, projectors, dynamic mathematics software (e.g., GeoGebra), and stable internet access to ensure effective implementation of virtual and technology-based instructional strategies.

3. Curriculum planners and examination bodies should formally integrate virtual and technology-based instructional activities into senior secondary school mathematics schemes of work and assessment. This will encourage teachers to embed technology consistently and enable students to gain sustained exposure to innovative approaches in calculus learning.

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