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Effect of GeoGebra on Secondary School Students' Attitudes and Retention in Solid Geometry in Benue State, Nigeria

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Abstract

Negative attitudes toward geometry and poor retention of geometric concepts continue to hinder students' learning outcomes in Nigerian secondary schools. This study investigated the effect of GeoGebra on secondary school students' attitudes toward learning and retention of solid geometry concepts in Benue State, Nigeria. A quasi-experimental pre-test–post-test non-equivalent control group design was adopted. The study involved 381 Senior Secondary School Two (SS2) students selected from two public secondary schools in Zone C of Benue State. Intact classes were assigned to the experimental ($n = 191$) and control ($n = 190$) groups. Data were collected using the Solid Geometry Attitude Questionnaire (SGAQ) and a Solid Geometry Retention Test (SGRT). The SGAQ yielded a Cronbach's alpha reliability coefficient of 0.81, while the SGRT produced a test–retest reliability coefficient of 0.84. The experimental group received GeoGebra-based instruction, whereas the control group was taught using the conventional method over eight weeks. Mean and standard deviation were used to answer the research questions, while Analysis of Covariance (ANCOVA) was employed to test the hypotheses at the 0.05 level of significance. The findings revealed that students taught using GeoGebra developed significantly more positive attitudes toward solid geometry ($F(1, 378) = 154.22$, $p < .001$, partial $\eta^2 = .290$) and achieved significantly higher retention of geometry concepts ($F(1, 378) = 172.88$, $p < .001$, partial $\eta^2 = .314$) than those taught using the conventional method. The study concluded that GeoGebra is an effective instructional tool for improving students' attitudes and long-term retention of solid geometry concepts. It is recommended that GeoGebra be integrated into secondary school mathematics instruction.

Keywords: *GeoGebra, attitude, retention, solid geometry, mathematics education, secondary school students.*

Introduction

Mathematics is widely recognized as a foundational discipline for scientific advancement and technological innovation. Within mathematics, geometry plays a critical role in developing learners' visualization, logical reasoning, and problem-solving abilities, which are essential for success in science, technology, engineering, and mathematics (STEM). Among the geometry topics taught at the secondary school level, solid geometry is particularly demanding because it requires students to understand three-dimensional objects, spatial relationships, and geometric transformations. However, despite its importance, students continue to demonstrate poor learning outcomes in solid geometry, not only in terms of achievement but also in their attitudes toward the subject and their ability to retain learned concepts (Idowu & Omotosho, 2021).

Students' attitudes toward mathematics, particularly geometry, have attracted considerable attention because attitude influences learners' motivation, confidence, engagement, and persistence in solving mathematical problems. Positive attitudes encourage active participation and meaningful learning, whereas negative attitudes often result in anxiety, avoidance of geometry-related tasks, and poor classroom engagement. Several studies have shown that students who develop positive attitudes toward mathematics are more likely to achieve higher academic outcomes and demonstrate greater willingness to engage in complex problem-solving activities (Awofala, 2022; OECD, 2023). Unfortunately, geometry is frequently perceived by many secondary school students as one of the most abstract and difficult areas of mathematics, leading to reduced interest and limited classroom participation.

Beyond attitude, retention of mathematical concepts remains a major concern in mathematics education. Effective learning extends beyond immediate achievement; students should be able to retain and apply concepts long after instruction has ended. In geometry, retention depends largely on conceptual understanding rather than rote memorization of formulas and procedures. Students who develop meaningful conceptual understanding are better able to recall, transfer, and apply geometric knowledge to unfamiliar situations. However, studies continue to report that many students quickly forget geometry concepts after instruction because learning is often based on memorization rather than active conceptual construction (National Council of Teachers of Mathematics [NCTM], 2023).

One factor contributing to students' negative attitudes and weak retention is the continued reliance on conventional teacher-centred instructional methods. In many Nigerian secondary schools, geometry is taught primarily through lectures, textbook illustrations, and static chalkboard diagrams. Although these methods may facilitate procedural knowledge, they provide limited opportunities for learners to interact with geometric objects, explore mathematical relationships, or construct knowledge through active participation. Consequently, students often perceive geometry as difficult, lose interest in the subject, and fail to retain important concepts beyond the classroom.

The integration of educational technology into mathematics instruction offers promising opportunities to improve students' learning experiences. GeoGebra, a dynamic mathematics software package, enables students to construct, manipulate, and visualize geometric objects interactively. Through its dynamic environment, learners can explore geometric relationships, receive immediate visual feedback, and actively participate in concept development. Such interactive learning experiences have been associated with improved motivation, positive attitudes toward mathematics, deeper conceptual understanding, and better long-term retention of learned concepts (Bakar et al., 2020; Jelatu et al., 2018).

Although previous studies have reported the benefits of GeoGebra in mathematics education, much of the available evidence has focused primarily on students' achievement and spatial reasoning. Comparatively fewer studies have investigated its influence on students' attitudes toward learning geometry and their retention of geometry concepts, particularly within the Nigerian secondary school context. Furthermore, empirical evidence from Benue State remains scarce despite increasing efforts to integrate digital technologies into classroom instruction.

This study therefore investigated the effect of GeoGebra on secondary school students' attitudes and retention in solid geometry in Benue State, Nigeria. Specifically, the study examined whether instruction supported by GeoGebra could improve students' attitudes toward learning solid geometry and enhance their retention of geometry concepts when compared with the conventional teaching method.

Statement of the Problem

Despite continuous efforts to improve mathematics education in Nigeria, many secondary school students continue to develop negative attitudes toward geometry and demonstrate poor retention of geometry concepts. Reports from classroom teachers and examination bodies suggest that many students perceive geometry as abstract, difficult, and uninteresting. Consequently, they often exhibit low motivation, limited classroom participation, mathematics anxiety, and an inability to retain geometric concepts beyond the period of instruction. These challenges reduce students' confidence and limit their ability to apply previously learned concepts when solving new mathematical problems.

Ideally, geometry instruction should promote positive attitudes toward learning while enabling students to develop lasting conceptual understanding and retain knowledge for future application. Learners should actively participate in the learning process, interact with geometric concepts through meaningful experiences, and develop sufficient interest and confidence to sustain long-term learning. Technology-supported instructional approaches, particularly those that encourage visualization and exploration, are expected to create engaging learning environments that enhance both students' attitudes and concept retention.

GeoGebra has emerged as one of the most widely used dynamic mathematics software applications for promoting interactive geometry learning. By allowing students to manipulate geometric objects and receive immediate visual feedback, GeoGebra has the potential to increase students' interest in learning geometry while strengthening conceptual understanding and retention. However, evidence regarding its effectiveness in improving students' attitudes toward learning solid geometry and their retention of geometry concepts in Benue State remains limited.

It is this lack of context-specific empirical evidence that constitutes the problem addressed by this study. Specifically, it remains unclear whether integrating GeoGebra into solid geometry instruction can significantly improve secondary school students' attitudes toward learning and their retention of geometry concepts compared with the conventional teaching method. This study therefore seeks to provide empirical evidence that can guide classroom practice, teacher professional development, and educational policy on the effective integration of GeoGebra into mathematics instruction.

Purpose of the Study

The purpose of this study was to investigate the effect of GeoGebra on secondary school students' attitudes toward learning and retention of solid geometry concepts in Benue State, Nigeria. Specifically, the study sought to:

1. determine the effect of GeoGebra on secondary school students' attitudes toward learning solid geometry; and

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2. examine the effect of GeoGebra on students' retention of solid geometry concepts.

Research Questions

The study was guided by the following research questions:

1. What is the effect of GeoGebra on secondary school students' attitudes toward learning solid geometry?
2. What is the effect of GeoGebra on students' retention of solid geometry concepts?

Null Hypotheses

The following null hypotheses were tested at the 0.05 level of significance:

H_{01}: There is no significant difference in the attitudes of students taught solid geometry using GeoGebra and those taught using the conventional teaching method.

H_{02}: There is no significant difference in the retention of solid geometry concepts between students taught using GeoGebra and those taught using the conventional teaching method

Methodology

This study employed a quasi-experimental pre-test–post-test non-equivalent control group design to investigate the effect of GeoGebra on secondary school students' attitudes toward learning solid geometry and their retention of geometry concepts. The design was appropriate because intact classes were used, making random assignment of individual students impracticable in the school setting (Creswell & Creswell, 2023). Two intact SS2 classes from different public secondary schools were assigned to the experimental and control groups. Both groups completed a pre-test before the instructional intervention, a post-test immediately after the intervention, and a delayed retention test four weeks later.

The design is represented as follows:

Experimental Group: O_1 × O_2 O_3
Control Group: O_1 — O_2 O_3

Where:
O_1 = Pre-test (Attitude Questionnaire)
× = GeoGebra-based instruction
— = Conventional instruction
O_2 = Post-test (Attitude Questionnaire)
O_3 = Delayed retention test

The study was conducted in Zone C of Benue State, Nigeria. The target population comprised 50,913 Senior Secondary School Two (SS2) students enrolled in 39 public secondary schools during the 2024/2025 academic session (Benue State Secondary Education Board [BSSEB], 2024). Using the Krejcie and Morgan (1970) sample size table, a sample of 381 students was selected. Two public secondary schools with functional computer laboratories were purposively selected, after which one school was randomly assigned to the experimental group (n = 191) and the other to the control group (n = 190). Intact SS2 classes from the selected schools participated in the study. Data were collected using the Solid Geometry Attitude Questionnaire (SGAQ) and a Solid Geometry Retention Test (SGRT). The SGAQ is a researcher-developed 20-item five-point Likert-scale questionnaire designed to measure students' attitudes toward learning solid geometry across four dimensions: enjoyment, perceived value, motivation, and self-belief. Responses ranged from Strongly Agree (5) to Strongly Disagree (1)**,** with negatively worded items reverse scored.

The SGRT consisted of structured solid geometry questions covering three-dimensional shapes, volumes, surface areas, coordinate geometry, and geometric transformations. The test was administered four weeks after the instructional intervention to assess students' retention of geometry concepts.

Both instruments were subjected to face and content validation by five experts in mathematics education and educational measurement. The SGAQ yielded a Cronbach's alpha coefficient of 0.81, while the SGRT produced a test–retest reliability coefficient of 0.84, indicating acceptable reliability. Before the commencement of the study, ethical approval and permission were obtained from the relevant educational authorities and participating schools. Mathematics teachers in the experimental school received training on the use of GeoGebra for teaching solid geometry.

Both groups completed the SGAQ before instruction commenced. The experimental group received GeoGebra-based instruction, while the control group was taught the same solid geometry topics using the conventional teacher-centred method. The intervention lasted eight weeks, with both groups covering identical curriculum content and receiving equal instructional time.

Immediately after the intervention, the SGAQ was re-administered to assess changes in students' attitudes. Four weeks later, both groups completed the Solid Geometry Retention Test to determine the extent to which they retained the concepts learned during the intervention.

Data were analysed using the Statistical Package for the Social Sciences (SPSS) version 27. Mean and standard deviation were used to answer the research questions. Analysis of Covariance (ANCOVA) was employed to test the null hypotheses at the 0.05 level of significance, using pre-test scores as covariates to control for initial differences between the experimental and control groups. Effect sizes (partial η^2) were reported to determine the magnitude of the treatment effects.

Results

Research Question 1: What are the attitudes of students toward learning solid geometry when GeoGebra is used as a teaching tool, compared to conventional methods?

Table 3 presents the descriptive statistics for the Solid Geometry Attitude Questionnaire (SGAQ) scores for both groups at baseline (pre-assessment) and after the intervention (post-assessment). A score of 50 or above is interpreted as a positive attitude; a score below 50 is interpreted as a negative attitude.

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Table 1: Descriptive Statistics for Students' Attitudes towards Solid Geometry

Group	N	Pre-Att. Mean	Pre-Att. SD	Post-Att. Mean	Post-Att. SD	Mean Change
Experimental (GeoGebra)	191	48.27	6.70	73.78	8.57	+25.51
Control (Conventional)	190	47.62	7.69	52.61	9.28	+5.00 (±0.01)

Note: Maximum score = 100; Minimum score = 20. Scores ≥ 50 = positive attitude; scores < 50 = negative attitude.

Table 1 shows that both groups entered the study with marginally negative baseline attitudes toward solid geometry (Experimental: M = 48.27, SD = 6.70; Control: M = 47.62, SD = 7.69), both slightly below the 50-point threshold for positive attitude. Following the eight-week intervention, the experimental group's mean attitude score rose dramatically to 73.78 (SD = 8.57) a mean change of +25.51 points, representing a strong shift to a positive attitude toward solid geometry. The control group's mean attitude score also improved slightly to 52.61 (SD = 9.28) a mean change of only +5.00 points, just crossing the positive attitude threshold. The 21.17-point difference in post-intervention attitude means strongly suggests that GeoGebra instruction produced substantially more positive attitudes toward solid geometry than conventional instruction.

Research Question 2: To what extent does GeoGebra improve students' retention of solid geometry concepts, particularly in visualizing three-dimensional shapes and spatial relationships?

Table 2: Descriptive Statistics for Students' Retention of Solid Geometry Concepts

SN	Group	N	Post-test Mean	Post-test SD	Retention Mean	Retention SD	Retention Index (%)
A	Experimental (GeoGebra)	191	72.05	9.02	67.49	10.75	93.7%
B	Control (Conventional)	190	50.58	9.90	44.25	10.26	87.5%

Note: Scores are out of 100. Retention Index = (Retention Mean / Post-test Mean) × 100.

Table 2 reveals that the experimental group retained substantially more of their post-test learning than the control group. The experimental group's delayed retention mean (M = 67.49, SD = 10.75) represents a retention index of 93.7%, meaning that the GeoGebra group retained 93.7% of their post-test performance level over the four-week delay. The control group's delayed retention mean (M = 44.25, SD = 10.26) represents a retention index of 87.5%, indicating that the control group retained a smaller proportion of their post-test gains. The absolute difference between the groups' retention means (67.49 – 44.25 = 23.24 points) is substantial, and the higher retention index of the experimental group (93.7% vs. 87.5%) suggests that GeoGebra instruction produced not only higher immediate performance but also more durable conceptual learning that persisted better over time.

Hypothesis Three $H0_3$: There is no significant difference in students' attitudes toward learning solid geometry when GeoGebra is used compared to conventional teaching methods.

Table 3: ANCOVA Summary for the Effect of GeoGebra on Students' Attitudes Toward Solid Geometry

SN	Source of Variation	df	F	p-value	Partial η²	Decision
A	Covariate (Pre-test Score)	1	138.44	.000	.218	Significant
B	Instructional Method (GeoGebra vs. Conventional)	1	154.22	.000	.290	
C	Error	378				
	Total	380				

Note: df = degrees of freedom; F = F-ratio; p = significance value; Partial η² = effect size. Level of significance = .05.

The ANCOVA results in Table 7 show that, after controlling for baseline attitude scores (F(1,378) = 138.44, p = .000), there was a statistically significant effect of instructional method on students' attitudes toward solid geometry (F(1,378) = 154.22, p = .000, partial η^2 = .290). Since the p-value of .000 is less than the .05 significance threshold, the null hypothesis $H0_3$ is rejected. The partial eta squared of .290 indicates a large effect size: instructional method accounted for 29.0% of the post-assessment attitude variance after controlling for baseline attitude. The adjusted post-assessment mean for the experimental group (Madj = 73.61) was significantly higher than the adjusted mean for the control group (Madj = 52.80), confirming that students who learned solid geometry through GeoGebra developed significantly more positive attitudes toward solid geometry learning than students who received conventional instruction.

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Hypothesis Four $H0_4$: The use of GeoGebra does not significantly improve students' understanding and retention of solid geometry concepts, particularly in visualising three-dimensional objects.

Table 4: ANCOVA Summary for the Effect of GeoGebra on Retention of Solid Geometry Concepts

SN	Source of Variation	df	F	p-value	Partial η^2	Decision
A	Covariate (Pre-test Score)	1	141.78	.000	.218	Significant
B	Instructional Method (GeoGebra vs. Conventional)	1	172.88	.000	.314	
C	Error	378				
	Total	380				

Note: The pre-test score was used as the covariate. df = degrees of freedom; F = F-ratio; p = significance value; Partial η^2 = effect size. Level of significance = .05.

The ANCOVA results in Table 8 indicate that, after controlling for pre-test scores ($F(1,378) = 141.78$, $p = .000$), instructional method had a statistically significant effect on students' delayed retention of solid geometry concepts ($F(1,378) = 172.88$, $p = .000$, partial $\eta^2 = .314$). The p-value of .000 is less than the .05 level of significance, and the null hypothesis $H0_4$ is therefore rejected. The partial eta squared value of .314 indicates a large effect: instructional method accounts for 31.4% of the variance in delayed retention scores after controlling for pre-test differences. The adjusted delayed retention mean of the experimental group (Madj = 67.32) was significantly higher than the adjusted delayed retention mean of the control group (Madj = 44.43). This finding confirms that GeoGebra significantly improved students' understanding and long-term retention of solid geometry concepts, particularly those involving the visualisation of three-dimensional shapes and spatial relationships. The superior retention of the experimental group is consistent with the theoretical prediction that GeoGebra's active, three-dimensional, discovery-oriented learning environment creates richer and more durable cognitive representations of solid geometry concepts than the passive reception of blackboard-mediated conventional instruction.

Discussion

The study found that GeoGebra significantly improved students' attitudes toward learning solid geometry compared with the conventional teaching method. Students exposed to GeoGebra developed more positive attitudes, as reflected in higher post-intervention attitude scores and the significant ANCOVA result. This finding suggests that the interactive and visual features of GeoGebra enhanced students' interest, confidence, and engagement in learning geometry. By allowing students to manipulate three-dimensional objects and receive immediate visual feedback, GeoGebra transformed geometry learning from a passive activity into an active and meaningful learning experience.

The finding is consistent with previous studies that reported positive effects of GeoGebra on students' attitudes toward mathematics and geometry. For example, Hohenwarter et al. (2009) found that GeoGebra-based instruction increased students' enjoyment and confidence in learning mathematics, while Tran et al. (2014) reported significant improvements in students' motivation and attitudes following an eight-week GeoGebra intervention. Similarly, Naidoo and Govender (2014) observed that students taught with GeoGebra developed more favourable attitudes toward geometry than those taught using conventional methods. The present finding also agrees with Ogbonnaya (2020), who reported positive attitudinal changes among Nigerian secondary school students following technology-supported mathematics instruction. However, the larger effect observed in the present study may reflect the novelty of GeoGebra in the study area, where students had limited prior exposure to technology-enhanced mathematics instruction. This finding provides further evidence that GeoGebra can promote positive attitudes toward geometry across different educational contexts, including public secondary schools in Benue State.

The study further revealed that GeoGebra significantly enhanced students' retention of solid geometry concepts. Students in the experimental group retained a greater proportion of the concepts learned during instruction than those in the control group, indicating that GeoGebra promoted more durable learning. The dynamic learning environment created by GeoGebra likely enabled students to develop deeper conceptual understanding through exploration, visualization, and active manipulation of geometric objects, thereby strengthening long-term memory of the concepts learned.

This finding corroborates the work of Bulut et al. (2016), who reported that GeoGebra facilitated deeper conceptual understanding and improved students' retention of geometry concepts. It also supports the findings of Saha et al. (2010), who found that students taught using GeoGebra retained geometry concepts significantly better than those taught through conventional methods after a delayed post-test. Similarly, Uwingabiye et al. (2022) reported that GeoGebra significantly improved students' long-term retention of geometry concepts in Rwandan secondary schools. The consistency of these findings across different educational contexts suggests that GeoGebra provides an effective instructional environment for promoting meaningful learning and sustained retention of mathematical concepts. The present study contributes additional empirical evidence from Nigeria, where research on technology-assisted geometry instruction remains relatively limited.

Overall, the findings indicate that GeoGebra is not only effective in improving students' cognitive learning outcomes but also in fostering positive attitudes and enhancing long-term retention of geometry concepts. These outcomes reinforce the value of integrating dynamic mathematics software into secondary school geometry instruction as a strategy for improving students' engagement and sustaining learning beyond the immediate instructional period.

Conclusion

This study investigated the effect of GeoGebra on secondary school students' attitudes toward learning and retention of solid geometry concepts in Benue State, Nigeria. The findings revealed that students exposed to GeoGebra developed significantly more positive attitudes toward learning solid geometry than those taught using the conventional teaching method. The study also established that GeoGebra significantly enhanced students' retention of solid geometry concepts, as evidenced by the higher delayed retention scores recorded by the experimental group. These findings suggest that the interactive and visual learning environment provided by GeoGebra promotes students' interest, confidence, and meaningful engagement with geometry, leading to improved long-term retention of learned concepts. The study therefore concludes that GeoGebra is an effective instructional tool for fostering positive attitudes and sustaining students' learning of solid geometry in secondary schools.

Recommendations

Based on the findings and conclusion of this study, the following recommendations are made:

1. Mathematics teachers should integrate GeoGebra into the teaching of solid geometry to promote positive learning attitudes and improve students' long-term retention of geometry concepts.
2. School administrators and education authorities should provide functional computer laboratories, appropriate digital infrastructure, and technical support to facilitate the effective use of GeoGebra in mathematics classrooms.
3. Curriculum planners and policymakers should incorporate GeoGebra and other dynamic mathematics software into the implementation of the senior secondary school mathematics curriculum, particularly for geometry instruction.
4. Teacher education institutions and professional development providers should organize regular workshops and in-service training programmes to equip mathematics teachers with the pedagogical and technological competencies required for effective GeoGebra-based instruction.
5. Researchers should replicate this study in other states, educational levels, and mathematics topics to further validate the effectiveness of GeoGebra and explore its influence on other learner outcomes, such as problem-solving, critical thinking, and mathematical creativity.

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