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Effect of Geogebra on Students' Mathematical Thinking Skills in Solving Geometry among Senior Secondary School Students in Sokoto State, Nigeria

Ahmad Adamu*, Muhammad Nasiru Hassan, Faruku Aliyu

Sokoto State University

***Corresponding author:** adamuahmad83@gmail.com

Abstract

This study investigated the effect of GeoGebra on the mathematical thinking skills of senior secondary school students in solving geometry problems in Sokoto State, Nigeria. A quasi-experimental pre-test–post-test non-equivalent control group design was adopted. The population comprised Senior Secondary School II (SS II) students in public secondary schools in Sokoto State. Two public schools with functional computer laboratories were purposively selected, and one intact class in each school provided the 118 participants (58 experimental, 60 control). The experimental group was taught geometry with GeoGebra and the control group with the demonstration method for (40 minutes, 6 weeks and 18 lessons). Data were collected with the Mathematical Thinking Skills Test (MTST), whose test–retest reliability coefficient (Pearson product-moment correlation) was 0.86. Data were analysed with descriptive statistics and independent-samples *t*-tests at the 0.05 level of significance. Post-test scores of the GeoGebra group ($M = 69.53$, $SD = 5.82$) were significantly higher than those of the demonstration group ($M = 56.27$, $SD = 6.41$), $t(116) = 11.75$, $p < .001$, mean difference = 13.26, 95% CI [11.03, 15.49], Cohen's $d = 2.16$. Within the GeoGebra group, female students ($M = 74.87$, $SD = 5.21$) scored higher than male students ($M = 71.60$, $SD = 5.84$), $t(56) = 2.24$, $p = .029$, $d = 0.59$; this difference is interpreted cautiously because it comes from a single class. Because the groups were intact classes, one per arm, the treatment effect cannot be separated from school and teacher effects. It is recommended that GeoGebra be used in geometry teaching in schools with adequate computer facilities, and that larger multi-school studies be conducted.

Keywords: GeoGebra, mathematical thinking, geometry, dynamic geometry software, gender, senior secondary school, quasi-experiment

1 Introduction

Geometry is the branch of mathematics concerned with the properties, measurement and relationships of shapes, sizes and positions in two and three dimensions. Mathematics is essential to science, technology, engineering and mathematics (STEM) fields, yet its perceived difficulty discourages many students from pursuing them (Li & Schoenfeld, 2019). Spatial and geometric reasoning in particular is described as a critical attribute for entry into and success in STEM professions, including engineering, architecture and robotics (Thom et al., 2024). Geometry learning is also closely tied to the development of mathematical thinking, as van Hiele-based studies of students' geometric thought in Nigeria show (Atebe, 2009). Mathematical thinking in geometry involves specialising, generalising, conjecturing and convincing (Mason et al., 2010), together with logical reasoning and spatial visualisation (Atebe, 2009; Schoenfeld, 1992). Its development depends on how geometry is taught. In a study of students in Sokoto State, Hassan et al. (2023) found weak foundational geometry skills, with most basic and senior secondary students at van Hiele level 0, and teachers reported that traditional teaching is the dominant approach in classrooms. Atebe (2009) likewise found that most Nigerian and South African learners were not ready for formal deductive geometry, with Nigerian learners more often at level 0. Ameen and Salman (2016) found that students in Kwara State identified many mathematics concepts as difficult to learn, and recommended that teachers vary their teaching methods.

These findings suggest the value of dynamic geometry software such as GeoGebra, which lets learners construct and manipulate figures, observe relationships and test conjectures. Recent reviews and experiments report that GeoGebra improves students' understanding of mathematical concepts (Azis & Rohaeti, 2025; Gurmu et al., 2024). The present study therefore examines the effect of GeoGebra on the mathematical thinking skills of senior secondary school students in solving geometry problems in Sokoto State.

1.1 Statement of the Problem

Secondary school students are expected to master geometric concepts. In Nigeria, and in Sokoto State in particular, however, many students lack basic geometry skills: Hassan et al. (2023) found most Sokoto State students tested to be at the lowest van Hiele level. The West African Examinations Council Chief Examiner's report on General Mathematics Paper 2, WASSCE (school candidates), 2023, listed among candidates' weaknesses "inadequate knowledge of Bearing, Angle of Elevation and Depression, Plane Geometry and Circle Geometry" and advised teachers to pay more attention to diagram-related topics, especially bearing, circle geometry and graphs (WAEC, 2023). Nationally, only 44.29% of private candidates in the November/December 2023 WASSCE obtained credit in at least five subjects including English Language and Mathematics (Advocate.ng, 2024).

Hassan et al. (2023) reported that traditional teaching is the dominant approach in Sokoto State classrooms, which leaves little room for active engagement and discovery. Studies of GeoGebra in Nigeria, however, have mostly measured academic achievement, performance or interest (for example Adigun & Aasa, 2023; Bassey & Ogbonna, 2023; Efor, 2025; Saidu, 2019). None of the Nigerian studies located measured mathematical thinking in geometry, and none was conducted in Sokoto State. This study addresses that gap.

1.2 Purpose of the Study

The purpose of this study was to examine the effect of GeoGebra on the mathematical thinking skills of senior secondary school students in solving geometry problems in Sokoto State, Nigeria, and to determine whether the thinking skills of male and female students taught with GeoGebra differ.

1.3 Research Questions

1. What are the mean mathematical thinking skills scores of students taught geometry using GeoGebra and those taught using the demonstration method?
2. What are the mean mathematical thinking skills scores of male and female students taught geometry using GeoGebra?

1.4 Research Hypotheses

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

H01: There is no significant difference in the mathematical thinking skills scores of students taught geometry using GeoGebra and those taught using the demonstration method.

H02: There is no significant difference in the mathematical thinking skills scores of male and female students taught geometry using GeoGebra.

2 Theoretical Framework

The study is guided by constructivist learning theory (Piaget, 1952) and Cognitive Load Theory (Sweller, 1988; Sweller et al., 2011). Constructivism holds that learners actively build knowledge by interacting with their environment and fitting new experiences into what they already know, rather than receiving information passively. It stresses active participation, manipulation of concrete materials and discovery as conditions for meaningful learning (Piaget, 1970). GeoGebra supports this by letting learners drag and transform geometric objects and observe what stays constant. Specialising (trying particular cases), generalising (seeing patterns across cases) and conjecturing (predicting relationships), three of the four thinking processes described by Mason et al. (2010), are expected to benefit from this manipulation.

Cognitive Load Theory states that working memory is limited, so instruction should reduce unnecessary (extraneous) mental effort and free capacity for learning the material itself (Sweller, 1988; Sweller et al., 2011). In a demonstration lesson, students must hold a static diagram in mind while following an argument. GeoGebra's dynamic visualisation and immediate feedback are expected to lower this load. This should leave more capacity for testing conjectures and for convincing, the fourth process in Mason et al. (2010), which is giving reasons why a result holds. Neither theory predicts a

gender difference, so the gender question (Research Question 2) is treated as exploratory and is interpreted in light of the conflicting empirical evidence reviewed below.

3 Literature Review

3.1 Mathematical Thinking in Geometry

Mathematical thinking is a dynamic process in which people increase the complexity of their ideas by handling and extending their understanding. Mason et al. (2010) proposed that students solve problems successfully by applying four processes: specialising, which means trying special cases by looking at examples; generalising, which means looking for patterns and relationships; conjecturing, which means predicting relationships and results; and convincing, which means finding and communicating the reasons why something is true. Schoenfeld (1992) describes learning to think mathematically as involving problem-solving, metacognition and sense-making.

3.2 GeoGebra and Student Outcomes in Mathematics

Most Nigerian studies of GeoGebra have measured achievement, performance or interest. Bassey and Ogbonna (2023) used a pretest–posttest quasi-experimental design with Junior Secondary 2 students in two purposively selected schools in Akwa Ibom State and found that students taught with GeoGebra achieved significantly higher than the control group; GeoGebra was also reported to enhance motivation and positive attitude to mathematics. Adigun and Aasa (2023) studied 107 senior secondary students (53 experimental, 54 control) in two public schools in the Ogbomoso Education Zone of Oyo State and found that the GeoGebra group's post-test geometry performance differed substantially from that of the control group taught by conventional methods. Efor (2025) used a quasi-experimental pretest–posttest design with 80 SS3 students in two schools in Warri South, Delta State, and reported that GeoGebra-assisted instruction improved performance in coordinate geometry more than the lecture method. Saidu (2019), in a doctoral study of 210 first-year college of education students in the North-West zone of Nigeria, compared GeoGebra, web-based practice and lecture; students taught with GeoGebra performed significantly better than those taught by lecture and also showed significant attitude change toward coordinate geometry, whereas web-based practice produced no significant differences.

Evidence from outside Nigeria is similar. Gurmu et al. (2024), in a 10-week quasi-experiment with Grade 10 students in Ethiopia, found that GeoGebra combined with a collaborative approach had a greater effect on conceptual understanding of geometry than GeoGebra with a conventional approach or conventional teaching alone. Hutkemri (2014) found significant differences in the conceptual and procedural knowledge of limit functions of 284 high school students in Riau, Indonesia, by group and ability after GeoGebra-based instruction. A systematic review of 33 studies by Azis and Rohaeti (2025) found that the most frequently cited benefit of GeoGebra was improved understanding of mathematical concepts, and the most cited challenge was the need for a supplementary module to support its implementation.

3.3 Gender Differences

Findings on gender are mixed and mostly show no significant difference. Adigun and Aasa (2023) found no statistically significant difference between the performance of male and female students taught with GeoGebra, and Saidu (2019) found no significant gender difference in performance or attitude change across his three instructional methods. Efor (2025) found that male students showed slightly higher gains than females, but not significantly so. In van Hiele-based work in Nigeria and South Africa, gender results generally favoured male learners (Atebe, 2009). This mixed evidence provides the context for Research Question 2.

3.4 Research Gap

Almost all of the studies above measured achievement, performance, conceptual understanding or interest rather than mathematical thinking, and none of the Nigerian studies located was conducted in Sokoto State. The present study therefore adds evidence on whether GeoGebra can improve students' mathematical thinking in geometry in a different context.

4 Methodology

4.1 Research Design

A quasi-experimental pre-test–post-test non-equivalent control group design was used, represented as:

Experimental group: O1 X O2

Control group: O1 C O2

where O1 is the pre-test, O2 the post-test, X instruction with GeoGebra and C instruction by the demonstration method. Intact classes were used because individual random assignment would have disrupted normal school organisation. One intact SS II class in each of two schools was used: the GeoGebra (experimental) group was taught at Sultan Muhammad Maccido Institute for Qur'anic and General Studies (SMMIQGS) and the demonstration (control) group at Government Day Secondary School (GDSS) Mabera. Because only one class took part in each condition, in two different schools, school and teacher effects are confounded with the treatment. This threat to internal validity is acknowledged under Limitations.

4.2 Participants and Sampling

The population comprised the 31,875 SS II students enrolled in public secondary schools in Sokoto State (Sokoto State Ministry of Basic and Secondary Education, 2026). Two schools were purposively selected because each had a functional computer laboratory and was willing to participate: GDSS Mabera and SMMIQGS. One intact SS II class was drawn from each school, giving 118 students: 58 in the GeoGebra group (30 male, 28 female) and 60 in the demonstration group. No power analysis was carried out; the sample size was determined by the size of the two intact classes.

4.3 Instrument

Data were collected with the Mathematical Thinking Skills Test (MTST), a subjective test of three geometry items on circle theorems (the angle at the centre and at the circumference, angles on the same chord or arc, and the angle in a semicircle). It was adapted from an unpublished instrument (Hassan, 2025) and was designed to assess logical reasoning, visualisation, pattern recognition and abstract reasoning. Students had 40 minutes. Responses were scored with a pre-defined rubric that awards marks for sketching the diagram, stating the theorem and solving for the required angle; each item carries 5 marks. The MTST was validated by the research supervisor and two experts, one from the Department of Science Education, Usmanu Danfodiyo University, and one from the Department of Mathematics, Shehu Shagari College of Education, Sokoto. The two experts rated five criteria (scope and content, alignment of objectives with content, alignment with the Nigerian curriculum, format, and freedom from ambiguity) and agreed on 4 of 5 (80% agreement). Reliability was established in a pilot study with 30 SS II students at Giginya Memorial Secondary School. The MTST was administered twice, two weeks apart, and the Pearson product-moment correlation coefficient was 0.86. This coefficient shows the stability of scores over time; it is not a measure of internal consistency.

4.4 Procedure and Intervention

A pre-test was administered to both groups before the intervention. The intervention then lasted six weeks, with three 40-minute periods per week. Both groups were taught by the researcher, using lesson plans on circle geometry (Theorems I and II). The GeoGebra group used computers or tablets with GeoGebra, and a projector where available, to construct circles, chords and angles, to measure and compare angles on the same chord and to calculate unknown angles. The demonstration group was taught the same theorems by the demonstration method, using the chalkboard, circle diagrams and charts, a ruler, protractor and compass. Activities in both groups included guided practice and class discussion. The post-test was administered after the six weeks (March, 2026).

4.5 Data Analysis

Means and standard deviations were used to answer the research questions. The hypotheses were tested with independent-samples *t*-tests and, as a robustness check that does not assume normality, the Mann–Whitney *U* test, using SPSS version

21 at the 0.05 level of significance. Cohen's *d* and 95% confidence intervals were computed from the summary statistics. The tests reported here compare post-test scores.

4.6 Ethical Considerations

Approval was obtained from the Sokoto State Ministry of Basic and Secondary Education Sokoto, and Principal of both GDSS Mabera and SMMIQGS, Sokoto.

5 Results

Results are presented for each research question and hypothesis. The test statistics reported were recomputed from the group sizes, means and standard deviations given in Tables 1 and 3, and should be rechecked against the raw data.

Research Question 1: What are the mean mathematical thinking skills scores of students taught geometry using GeoGebra and those taught using the demonstration method?

Table **1**

Post-test mathematical thinking skills scores of the experimental and control groups

Group	N	Mean	Standard deviation	Mean difference
Experimental (GeoGebra)	58	69.53	5.82	13.26
Control (demonstration)	60	56.27	6.41	

Source: Fieldwork (2026).

The experimental group had a post-test mean of 69.53 (*SD* = 5.82) and the control group a mean of 56.27 (*SD* = 6.41), a difference of 13.26 points in favour of the GeoGebra group. The standard deviations are similar, so the spread of scores in the two groups did not differ meaningfully.

Hypothesis One (H01): There is no significant difference in the mathematical thinking skills scores of students taught geometry using GeoGebra and those taught using the demonstration method.

Table **2**

Independent-samples t-test of post-test mathematical thinking skills scores, by group

Group	N	Mean	SD	T	df	p	Cohen's d [95% CI of difference]	Decision
Experimental	58	69.53	5.82	11.75	116	< .001	2.16 [11.03, 15.49]	H01 rejected
Control	60	56.27	6.41					

Source: Fieldwork (2026). α = 0.05.

The GeoGebra group scored significantly higher than the demonstration group, $t(116) = 11.75$, $p < .001$, mean difference = 13.26, 95% CI [11.03, 15.49], Cohen's $d = 2.16$. A Mann–Whitney U test gave the same conclusion (mean ranks 32.53 and 85.58, $U = 175.50$, $Z = -8.43$, $p < .001$, $r = .78$). H01 is therefore rejected. An effect of this size is unusually large for an educational intervention. Taken together with the lack of pre-test analysis by group and the use of one intact class per group, it should be read with caution: the difference may partly reflect initial differences between the two classes, school or teacher effects, or the novelty of the software, and not only the instructional method.

Research Question 2: What are the mean mathematical thinking skills scores of male and female students taught geometry using GeoGebra?

Table **3**

Post-test mathematical thinking skills scores of male and female students taught with GeoGebra

Gender	N	Mean	Standard deviation	Mean difference

Male	30	71.60	5.84	3.27
Female	28	74.87	5.21	

Source: Fieldwork (2026).

Within the GeoGebra group, male students obtained a mean score of 71.60 (*SD* = 5.84) and female students 74.87 (*SD* = 5.21), so females scored 3.27 points higher after the instruction.

Hypothesis Two (H02): There is no significant difference in the mathematical thinking skills scores of male and female students taught geometry using GeoGebra.

Table **4**

Independent-samples t-test of post-test mathematical thinking skills scores of male and female students taught with GeoGebra

Gender	**N**	**Mean**	**SD**	**T**	**df**	**p**	**Cohen's d [95% CI of difference]**	**Decision**
Male	30	71.60	5.84	2.24	56	.029	0.59 [0.35, 6.19]	H02 rejected
Female	28	74.87	5.21					

Source: Fieldwork (2026). α = 0.05. Recomputed from the summary statistics; the values in the submitted manuscript (t = 1.61, df = 28, p = .000) were inconsistent with these data.

Female students scored significantly higher than male students, $t(56) = 2.24$, $p = .029$, mean difference = 3.27, 95% CI [0.35, 6.19], Cohen's $d = 0.59$. H02 is therefore rejected at the 0.05 level. The result is only just significant and comes from small subgroups in a single class. Gender was analysed only within the GeoGebra group, so the data show that females scored higher after instruction; they do not show that females benefited more from GeoGebra than males did, which would require a comparison with the demonstration group (a method × gender interaction) controlling for pre-test scores.

6 Discussion

GeoGebra and mathematical thinking. Students taught with GeoGebra scored higher on the MTST than those taught by the demonstration method. This agrees in direction with Nigerian studies in which GeoGebra groups outperformed control groups in achievement or performance (Adigun & Aasa, 2023; Bassey & Ogbonna, 2023; Efor, 2025; Saidu, 2019) and with evidence of improved conceptual understanding of geometry elsewhere (Gurmu et al., 2024). Those studies measured achievement or conceptual understanding, not mathematical thinking, and Bassey and Ogbonna worked with junior secondary students, so they support the direction of the present finding but not directly its conclusion about thinking skills. A plausible explanation, consistent with the theoretical framework, is that dynamic manipulation and immediate feedback support specialising, generalising and conjecturing and lower extraneous cognitive load. The study collected no process data (such as observations or students' working), so this mechanism was not tested.

The size of the difference ($d = 2.16$) is much larger than is usual in educational research. Alternative explanations include pre-existing differences between the two intact classes (no pre-test analysis is reported), school and teacher effects, the novelty of the software and the unstated length of the intervention.

Gender. Female students in the GeoGebra group scored significantly higher than male students, but only just, with $p = .029$ and a moderate effect ($d = 0.59$). This differs from the studies reviewed, in which Adigun and Aasa (2023) and Saidu (2019) found no significant gender difference, Efor (2025) found slightly higher male gains that were not significant, and Atebe (2009) found results generally favouring males in van Hiele-based tests. Differences in content, level, instrument and context may account for the disagreement; in this study the difference may also reflect the composition of one class, since the groups were small and no pre-test comparison by gender was made. The result therefore cannot be taken to show that GeoGebra favours female students, and it needs replication with larger samples, several classes per condition and a comparison across both instructional methods.

7 Limitations

The main limitations are: (1) one intact class per condition, so school and teacher effects are confounded with treatment; (2) small samples (58 and 60; 30 males and 28 females in the GeoGebra class); (3) pre-test scores were not analysed by group, so baseline equivalence is unknown; (4) the intervention lasted only six weeks, and the researcher taught both groups, which allows for experimenter bias; (5) a single adapted three-item test on circle theorems was used, with a total score only and no separate scores for the sub-skills (logical reasoning, visualisation, pattern recognition, abstract reasoning), so the results cannot be generalised to all geometry topics; (6) only one state was covered, and only schools with functional computer laboratories; (7) there was no delayed post-test; and (8) gender was examined in the GeoGebra group only. Future research should use longer interventions, randomised or multi-school designs, ANCOVA with pre-test covariates, delayed post-tests and qualitative evidence of students' thinking processes.

8 Conclusion

Within the limits of the design, post-test mathematical thinking scores were significantly higher in the class taught geometry with GeoGebra than in the class taught by demonstration. Because the groups were two intact classes in two schools, this does not establish that GeoGebra caused the difference. Within the GeoGebra class, female students scored higher than male students by a moderate margin ($p = .029$), a result that should be treated as tentative. The study did not measure the separate sub-skills of mathematical thinking and did not compare gender differences across instructional methods, so no conclusions are drawn about these.

9 Recommendations

Based on the findings, and bearing in mind that the study was carried out in schools with functional computer laboratories, the following recommendations are made:

(i) School administrators and state education authorities should provide functional computer laboratories, adequate GeoGebra installations, a reliable power supply and an adequate computer-to-student ratio in schools that teach SS II geometry, since GeoGebra use depends on access.

(ii) Teacher-training institutions and the Ministry of Education should provide in-service training for mathematics teachers in designing GeoGebra-based inquiry tasks that require specialising, generalising, conjecturing and convincing.

(iii) Curriculum planners should explore integrating GeoGebra activities into the senior secondary geometry scheme of work, after trials in a wider range of schools, including those with limited ICT facilities.

(iv) Researchers should replicate the study with larger, randomised or multi-school samples, report pre-test data and use ANCOVA before policy decisions are based on these findings.

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