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The Impact of GeoGebra-Assisted Instruction on Students' Performance in Geometric Construction: Exploring Teacher Beliefs and Classroom Practices

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ABSTRACT

Purpose – This study examined the effect of GeoGebra on students' performance in geometric construction, with emphasis on students' perceptions and teachers' beliefs and instructional practices in a Ghanaian senior high school context.

Methodology – Guided by Social Constructivist Theory, the Technology Acceptance Model, and Cognitive Load Theory, the study adopted a pragmatic paradigm using a convergent mixed-methods design. The research was conducted at Nkyeraa Senior High School in the Wenchi Municipality of Ghana. The sample comprised 71 Form 3 students selected into experimental and control groups and five mathematics teachers. Quantitative data were collected using pre-test and post-test achievement tests and a ten-item five-point Likert scale questionnaire on students' perceptions. Independent samples t-tests were used for data analysis. Qualitative data were gathered through semi-structured interviews with teachers and analyzed using thematic analysis.

Findings – Pre-test results showed no significant difference between the experimental and control groups, indicating equivalence. Post-test results revealed that students taught using GeoGebra performed significantly better than those taught through traditional methods. Students demonstrated positive perceptions of GeoGebra-assisted learning, with a grand mean score of 4.37. Four themes emerged from teacher interviews: beliefs about GeoGebra, perceived impact on learning, instructional strategies, and challenges and support needs.

Novelty – The study integrates students' achievement, perceptions, and teachers' beliefs within a single mixed-method framework in a Ghanaian senior high school setting.

Significance – The findings benefit mathematics teachers, curriculum developers, and policymakers by supporting the integration of GeoGebra, teacher professional development, and improved ICT infrastructure in mathematics education.

Keywords: Geogebra; Geometric construction; Students' mathematical performance; Teachers' beliefs.

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1. Introduction

The integration of Information and Communication Technology (ICT) in mathematics education has gained global recognition as a transformative tool for enhancing student learning outcomes (Barakabitze et al., 2019). Among these digital tools, GeoGebra has emerged as one of the most effective platforms for improving students' understanding of mathematical concepts, particularly in geometric construction. As an interactive dynamic mathematics software, GeoGebra allows students to explore, visualize, and manipulate geometric figures, fostering a deeper conceptual understanding and enhancing their problem-solving skills (Zhang et al., 2025).

Numerous international studies highlight the positive impact of ICT-based tools like GeoGebra on student engagement and overall mathematical performance. A meta-analysis by Drijvers (2015) found that students who used dynamic geometry software achieved higher levels and demonstrated better conceptual understanding than those who relied on traditional teaching methods. Similarly, Trouche (2019) found that digital mathematics environments enhance students' ability to construct, manipulate, and reason about mathematical objects, thereby improving their problem-solving strategies. These findings reinforce the argument that integrating GeoGebra into mathematics instruction can lead to significant improvements in students' learning experiences and outcomes.

Despite the well-documented benefits of GeoGebra, its adoption and effective integration into mathematics instruction remain inconsistent. One of the major factors influencing this variation is the disparity in teachers' levels of technological competence, pedagogical beliefs, and institutional support (Aidoo et al., 2022). While some educators embrace ICT as a pedagogical enabler, others remain skeptical of its effectiveness, creating gaps between teachers' beliefs and classroom practices. This reluctance can be attributed to various factors, including lack of training, limited access to digital resources, and concerns about the adaptability of ICT tools to existing teaching methodologies (Aidoo et al., 2022).

Globally, some regions have made significant strides in integrating ICT tools like GeoGebra into their mathematics curricula. In Asia, for instance, countries such as Singapore, China, and South Korea have successfully incorporated technology-enhanced learning strategies in mathematics instruction. Research by Li et al. (2021) in China found that students who learned geometric construction using GeoGebra performed better than their peers who were taught through conventional instructional methods. Similarly, Singapore's Mathematics Mastery Framework integrates GeoGebra as a tool to enhance visualization and critical thinking in geometry, demonstrating how strategic ICT integration can improve learning outcomes.

In Ghana, the use of ICT in education has been promoted through national policies such as the ICT in Education Policy (2015), which underscores the importance of technology-enhanced teaching. However, the implementation of digital tools such as GeoGebra in Ghanaian classrooms remains limited due to resource constraints, inadequate teacher training, and resistance to change. This implementation gap is even more pronounced in rural schools, where limited ICT infrastructure and teachers' reluctance to adopt new instructional strategies hinder the effective use of technology in teaching mathematics.

Nkyeraa Senior High School, located in the Wenchi Municipal District of the Bono Region, provides a relevant context for investigating the impact of GeoGebra on students' geometric construction performance. Like many other secondary schools in Ghana, Nkyeraa SHS faces challenges in ICT integration, including limited digital resources, teachers' varying levels of technological competence, and students' unfamiliarity with digital learning tools. These challenges contribute to difficulties in teaching and learning geometry-related topics, potentially affecting students' overall performance in mathematics. Given this context, it is crucial to explore how teachers' beliefs and instructional practices influence GeoGebra's effectiveness in improving students' mathematical learning outcomes. Understanding these factors will provide valuable insights into how ICT tools can be leveraged to enhance mathematics education, particularly in under-resourced schools.

Students' persistent underachievement in geometry, particularly in geometric construction, has become a major concern in Ghanaian Senior High Schools. Reports such as the 2023 West African Senior School Certificate Examination (WASSCE) Chief Examiner's Report indicate that students struggle with geometric concepts due to a lack of conceptual understanding, heavy reliance on rote memorization, and difficulty visualizing geometric constructions (WAEC, 2023). Additionally, Mensah et al. (2023) found that many mathematics teachers in Ghana acknowledge the potential of digital learning tools such as GeoGebra, but challenges, including limited training and inadequate institutional support, limit their effective use, thereby exacerbating students' difficulties in comprehending abstract mathematical concepts. Despite various educational interventions, student performance in this area remains low, particularly in rural schools like Nkyeraa Senior High School in the Wenchi Municipality of the Bono Region.

The integration of ICT-based instructional tools has been widely recognized as an effective strategy for improving students' mathematical performance. Studies such as Drijvers (2015) and Li et al. (2021) provide strong empirical evidence that dynamic geometry software like GeoGebra enhances students' achievement by allowing them to explore, manipulate, and construct geometric figures interactively. Similarly, Trouche (2019) emphasizes that digital mathematics environments strengthen students' reasoning and visualization skills, which are critical in geometric construction. However, despite these promising findings, students in Ghana continue to perform poorly in geometry, raising questions about whether the lack of ICT integration contributes to this trend.

Empirical studies in Ghana have explored the benefits of GeoGebra integration in mathematics education, but they often lack key variables that this study seeks to examine. For instance, Asare and Atteh (2022) found that students taught transformations with GeoGebra performed significantly better than those taught using traditional methods. However, their study did not examine how teachers' pedagogical beliefs and instructional strategies influenced GeoGebra's effectiveness. Likewise, Narh-Kert and Sabtiwu (2022) observed that GeoGebra promotes improved performance and engagement in geometry, but they did not examine how teachers' technological competence affects its implementation. These gaps are critical because research from technologically advanced countries, such as Singapore and China, has shown that structured teacher training and institutional support are significant factors in successful ICT integration (Li et al., 2021). In contrast, Ghanaian studies indicate that, despite national policy efforts to promote ICT in education, many teachers lack adequate ICT pedagogical training, limiting their ability to maximize the benefits of GeoGebra (Mensah et al., 2023).

Thus, while existing research acknowledges the potential of GeoGebra, there is limited empirical evidence on how teachers' beliefs, instructional strategies, and professional training influence its effectiveness in improving students' mathematical performance, particularly in geometric construction. This study seeks to bridge this gap by analyzing both the direct impact of GeoGebra on students' achievement and the role of teachers' pedagogical orientations in shaping its success. By focusing on Nkyeraa Senior High School in the Wenchi Municipality, this research will provide empirical insights to inform teacher training programs, policy implementation, and strategies for optimizing GeoGebra integration in mathematics instruction in Ghanaian schools.

Research Questions are (1) What are students' perceptions of GeoGebra in learning geometric construction?; (2) How do teachers' beliefs and instructional practices influence the effectiveness of GeoGebra in teaching geometric construction?

2. Methods

This study was guided by the pragmatic paradigm, which integrates both positivist and interpretivist perspectives to provide a comprehensive understanding of geogebra's impact on students' mathematical performance in geometric construction and the teachers' beliefs and practice. A convergent mixed-methods design was adopted, enabling the simultaneous collection and analysis of quantitative and qualitative data.

The population comprised of students and mathematics teachers at Nkyeraa Senior High School, located in the Wenchi Municipality. The school had a total student population of 257. The study involved 71 Form 3 students and 5 mathematics teachers from Nkyeraa Senior High School in Wenchi Municipality. Two intact classes were used: 36 students in the experimental group taught with GeoGebra and 35 in the control group taught traditionally. Purposive sampling was applied to align with the quasi-experimental design, while 5 of the 9 teachers were included to provide insights into their beliefs, practices, and challenges in integrating GeoGebra.

The study used three main instruments: a Mathematics Achievement Test, a Student Perception Questionnaire, and a Teacher Interview Guide supported by an observation checklist. The achievement test, aligned with the GES syllabus and validated by experts, was administered as pre- and post-tests to assess the impact of GeoGebra on students' geometric construction skills. The questionnaire, adapted from Arbain and Shukor (2015), measured students' perceptions across four dimensions usefulness, engagement, cognitive stimulation, and instructional preference using a Likert scale. The teacher interview guide, complemented by classroom observations, explored teachers' beliefs, practices, and challenges in integrating GeoGebra. Collectively, these instruments ensured comprehensive and reliable data for addressing the study's objectives.

Validity and reliability were ensured through expert reviews, pilot testing, and statistical analysis. The Mathematics Achievement Test was reviewed by curriculum specialists for content validity, piloted with non-sample students, and revised for clarity and difficulty. The Student Perception Questionnaire, adapted from validated instruments, underwent expert evaluation and pilot testing, with Cronbach's Alpha used to confirm internal consistency ($\alpha \geq 0.70$). These measures ensured that all instruments accurately measured the intended constructs and produced consistent, dependable results. Qualitative trustworthiness was established using Lincoln and Guba's (1985) framework of credibility, transferability, dependability, and confirmability.

The study employed both quantitative and qualitative analyses to address the research questions. Quantitative analysis used an independent samples t-test and Cohen's d to evaluate the effect of GeoGebra on students' performance (RQ1), and descriptive statistics (mean, SD, frequencies) to summarize students' perceptions (RQ2). Qualitative analysis applied Braun and Clarke's six-step thematic approach to teacher interviews, identifying beliefs, instructional practices, and challenges (RQ3). Triangulation with student questionnaire data enhanced the credibility of findings, ensuring a comprehensive understanding of GeoGebra's impact.

The study implemented a three-week intervention comparing GeoGebra-based and traditional instruction in geometric construction. The experimental group used GeoGebra to explore constructions such as bisecting lines, constructing perpendiculars, and building triangles and circles, with emphasis on interactive visualization, collaboration, and dynamic manipulation. The teacher received prior training to ensure effective integration of the software. The control group was taught the same content using traditional chalkboard methods and geometry sets. Both groups, taught by the same teacher, had six 50-minute lessons, with pre- and post-tests used to measure learning gains. Classroom observations in the experimental group provided additional insights into engagement and problem-solving behavior.

Ethical considerations were strictly observed. Informed consent was obtained from participants, anonymity and confidentiality were ensured, participation was voluntary, and approval was sought from relevant authorities.

3. Results and Discussion

3.1. Results

3.1.1 Test of Assumptions or Preliminary Analysis

Before applying an independent-samples t-test, it is critical to ensure that the necessary statistical assumptions are met to validate the results' accuracy and reliability. These assumptions are foundational to the test's integrity and must be rigorously tested. The three primary assumptions include independence of observations, normality, and homogeneity of variances. The first and most fundamental assumption is that of independence. This assumption requires that the observations or measurements within each group and between the two groups be independent of one another. In simpler terms, the score of one participant should not influence or be influenced by another participant's score. Each subject should belong to only one group and should contribute only one data point to the analysis.

In experimental or quasi-experimental educational research designs, this assumption is typically met when participants are assigned to separate groups (e.g., experimental and control) and taught under different instructional conditions, without overlap or interaction that could contaminate responses. The independence of observations ensures that the t-test compares truly independent groups. In this study, the assumption of independence is satisfied as the experimental and control groups consisted of different sets of students drawn from different intact classes. These groups were taught using different instructional approaches: GeoGebra for the experimental group and traditional methods for the control group, without any crossover or interference, thereby maintaining the integrity of independent sampling. The second assumption is normality, which implies that the distribution of the dependent variable (in this case, test scores) in each group approximates a normal (bell-shaped) distribution. The independent-samples t-test is a parametric test and is most robust when the data within each group are normally distributed.

Normality can be assessed visually (using histograms, Q-Q plots, or boxplots) and statistically using tests such as the Shapiro-Wilk or Kolmogorov-Smirnov tests. A non-significant result ($p > 0.05$) in these tests indicates that the data do not significantly deviate from normality, which justifies the use of parametric methods.

Table 1 - Test for Normality Across Groups for Various Tests

Test	Group	Kolmogorov-Smirnova			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pre-test	Control	.113	35	.200	.961	35	.237
	Experimental	.124	36	.177	.945	36	.073
Post-test	Control	.091	35	.200	.981	35	.778
	Experimental	.125	36	.172	.963	36	.259

In this study, both the Shapiro-Wilk and Kolmogorov-Smirnov tests were conducted for the pre-test and post-test scores in both the experimental and control groups. All p-values were above the 0.05 threshold, indicating that the data were normally distributed across all conditions. Therefore, the normality assumption was met, confirming the appropriateness of using the independent samples t-test.

The third assumption is homogeneity of variances, also known as equal variances. This assumption states that the variability (spread) of scores within one group should be similar to that within the other group. If the variances between the two groups differ significantly, the t-test results may be distorted, potentially inflating the Type I error rate. To test this assumption, Levene's Test for Equality of Variances is commonly used. A non-significant result ($p > 0.05$) indicates that the variances are not significantly different and the assumption is met.

Table 2 - Levene's Test for Equality of Variances

Test	F	Sig.
Pre-test	.272	.603
Post-test	.044	.834

In this study, Levene's test was conducted for both pre-test and post-test scores. The results yielded p-values of .603 for the pre-test and .834 for the post-test, both of which are above the 0.05 threshold. These findings indicate that the variances in both the experimental and control groups are statistically equal, satisfying the assumption of homogeneity of variances.

3.1.2 The Difference in the Academic Performance of Students

Before examining the impact of the GeoGebra intervention on students' mathematical performance, it was important to determine whether there were significant differences between the experimental and control groups prior to the treatment. This was done by comparing the pre-test scores of students in both groups using an independent samples t-test. The purpose of this analysis was to establish baseline equivalence between the groups, a necessary condition for attributing post-intervention performance differences to the treatment rather than pre-existing academic disparities.

Table 3 below presents the results of an independent t-test comparing the academic performance of students in the experimental and control groups before the treatment.

Table 3 - Independent t-test for Pre-Test Comparison of Academic Performance

Test	Group	N	Mean	SD	t	df	Sig.	Eta Sqrt
Pre-test	Control	35	29.57	4.38	.638	69	.525	0.006
	Experimental	36	28.80	5.62				

The findings of an independent-samples t-test, used to compare the pre-test mean scores for students' geometric construction performance between the control and experimental groups prior to the introduction of the GeoGebra intervention, are displayed in Table 3. The results indicate that the control group obtained (M = 29.57, SD = 4.38), while the experimental group obtained (M = 28.80, SD = 5.62). The independent-samples t-test revealed that the difference in means was not statistically significant [t(69) = 0.638, p = .525]. Since the p-value is greater than 0.05, the null hypothesis that there is no significant difference between the two groups before the treatment cannot be rejected.

An eta-squared effect size analysis yielded 0.006, indicating a very small effect (Cohen, 1988). This suggests that the difference in students' academic performance between the two groups prior to the intervention was negligible and had little to no practical significance.

The results demonstrate that there was no statistically significant difference in students' pre-test performance between the experimental and control groups. This implies that both groups had comparable levels of mathematical proficiency in geometric construction before the intervention. Such baseline equivalence is crucial in quasi-experimental research, as it strengthens the validity of any post-intervention comparison. It ensures that any observed differences in the post-test outcomes can be more confidently attributed to the intervention itself, in this case, the use of GeoGebra, rather than to pre-existing disparities in student ability.

3.1.3 The Difference in Students' Performance in Geometric Construction

This section presents the results of the independent-samples t-test conducted to determine whether there was a statistically significant difference in students' geometric construction performance after the intervention. Specifically, it compares the post-test scores of students in the experimental group, who were taught using GeoGebra, with those in the control group, who received instruction through traditional teaching methods. The purpose is to assess the effectiveness of GeoGebra as an instructional tool in enhancing students' understanding and performance in geometric construction.

Table 4 below presents the results of an Independent t-test for a post-test comparison of academic performance between traditional and GeoGebra use.

Table 4 - Independent t-test for Post-test Comparison of Academic Performance

Test	Group	N	Mean	SD	t	df	Sig.	Eta Sqrt
Post-test	Control	35	34.11	5.22	-5.820	69	.000	0.33
	Experimental	36	41.69	5.73				

The results of the independent-samples t-test comparing the post-test academic performance of students in the experimental and control groups are presented in Table 4. This analysis was conducted to evaluate the effect of a GeoGebra-based instructional strategy compared to the traditional method of teaching geometric construction.

The findings indicate that students in the experimental group, who were taught using GeoGebra, achieved a higher post-test mean score (*M = 41.69, SD = 5.73*) than their counterparts in the control group *(M = 34.11, SD = 5.22)*. The independent-samples t-test revealed a statistically significant difference between the two groups [t*(69) = -5.820, p < .001]*. Since the p-value is less than the conventional alpha level of 0.05, the result is considered statistically significant, and the null hypothesis is rejected. This indicates that the use of GeoGebra had a significant positive impact on students' academic performance in geometric construction.

Furthermore, an effect size was calculated using eta-squared to assess the practical significance of the observed difference. The computed eta squared value was 0.33. An eta squared value of 0.33 represents a large effect size according to Cohen's (1988) guidelines. This suggests that a substantial portion of the variation in students' post-test performance can be attributed to the instructional method, specifically the integration of GeoGebra into the teaching of geometric construction. These results strongly support the conclusion that students who were exposed to GeoGebra-based instruction performed significantly better than those taught using traditional methods. The improvement in performance may be due to GeoGebra's capacity to enhance visualization, promote active engagement, and support conceptual understanding in geometry. Therefore, it can be inferred that GeoGebra is an effective instructional approach for improving students' performance in geometric construction.

3.1.4 Students' Perceptions of GeoGebra in Learning Geometric Construction

This section presents an analysis of students' perceptions of the use of GeoGebra in geometric construction. The data were collected through a structured questionnaire designed to capture students' attitudes, confidence levels, engagement, and perceived benefits of using GeoGebra. The responses were measured on a 5-point Likert scale and analyzed using descriptive statistics to determine overall trends and insights into how students experienced the GeoGebra-based instructional approach.

Table 5 - Analysis of Students' Perceptions of GeoGebra in Learning Geometric Construction

Statement	Mean	SD
I enjoy learning geometry when GeoGebra is used in class.	4.50	.56
GeoGebra helps me better understand geometric construction concepts.	4.47	.55
I feel confident when doing geometric activities using GeoGebra.	4.44	.55
I can think more critically and creatively when I use GeoGebra to construct geometric figures.	4.38	.59
I prefer learning geometry with GeoGebra rather than with traditional tools like compasses and rulers.	4.36	.63
I am excited when asked to use GeoGebra to explore geometry.	4.38	.64
GeoGebra helps improve my performance in geometry.	4.25	.69
I would like my teacher to use GeoGebra more often during geometry lessons.	4.33	.63
I learn more in geometry when I use GeoGebra.	4.36	.63
GeoGebra makes learning geometric construction more fun and interactive.	4.27	.61
Grand Mean	4.37	.61

Source: Field Survey (2025)

To answer Research Question 2, "What are students' perceptions of GeoGebra in learning geometric construction?", a 10-item Likert-scale questionnaire was administered to students in the experimental group. The items explored various themes, including enjoyment, understanding, engagement, creativity, performance, and instructional preference. Responses were scored from 1 (Strongly Disagree) to 5 (Strongly Agree).

The grand mean score for the student responses was 4.37, with a standard deviation of 0.61. This indicates that, on average, students held very positive perceptions of GeoGebra as an instructional tool for learning geometric construction. The high mean and low variability suggest strong, consistent consensus among the students in favor of GeoGebra. This finding strongly supports the conclusion that students perceived GeoGebra as engaging, helpful, and effective, thereby positively contributing to their learning experiences in geometry.

A breakdown of individual item responses further reinforces this interpretation. The highest-rated statement was "I enjoy learning geometry when GeoGebra is used in class" (M = 4.50, SD = 0.56), indicating strong enthusiasm and engagement. Students also agreed that "GeoGebra helps me understand geometric construction concepts better" (M = 4.47) and "I feel confident when doing geometric activities using GeoGebra" (M = 4.44), indicating that the software supported both comprehension and self-efficacy.

Moreover, the perception that "I can think more critically and creatively when I use GeoGebra" (M = 4.38) points to the software's role in promoting higher-order thinking. The preference for digital tools over traditional ones is evidenced by strong agreement with the item "I prefer learning geometry with GeoGebra rather than with traditional tools like compasses and rulers" (M = 4.36).

Other notable items included "GeoGebra helps improve my performance in geometry" (M = 4.25) and "GeoGebra makes learning geometric construction more fun and interactive" (M = 4.27), both of which confirmed that students believed the tool positively influenced their academic outcomes and their enjoyment of learning. In summary, the high grand mean and consistently positive item responses provide strong evidence that students view GeoGebra as a valuable and effective resource for learning geometric construction. These findings affirm the potential of dynamic mathematics software to enhance engagement, understanding, and motivation in mathematics classrooms.

3.2. Discussions

Thematic analysis was used to analyze the qualitative data collected from five mathematics teachers at Nkyeraa Senior High School. This approach was appropriate for addressing the third objective of the study: To explore how teachers' beliefs and instructional practices influence the effectiveness of GeoGebra in teaching geometric construction. The analysis followed the six-phase method proposed by Braun and Clarke (2006), which provided a structured framework for identifying, organizing, and interpreting meaningful patterns within the interview data.

In the first phase, familiarization with the data was achieved by transcribing the recorded interviews verbatim and reading through the transcripts several times. This allowed the researcher to immerse themselves in the data and begin noticing recurring ideas, patterns, and important expressions related to teachers' beliefs, practices, and experiences with GeoGebra. Preliminary notes were taken in the margins to highlight significant responses and raise analytical questions.

The second phase involved generating initial codes. This was done manually by systematically highlighting relevant sections of the transcripts and assigning descriptive labels to meaningful data excerpts. For example, statements such as "GeoGebra makes it easier for students to visualize" or "I feel more confident when I use GeoGebra" were coded under categories such as visualization benefit, confidence in use, and pedagogical support. This coding helped to organize the data into smaller, manageable units for deeper analysis.

In the third phase, related codes were collated into potential themes. Codes that reflected similar meanings were grouped together. For instance, comments that referred to the usefulness of GeoGebra, its role in improving understanding, and its ease of use were clustered under the emerging theme Teachers' Beliefs about GeoGebra and Mathematics Instruction. This process was done across all five participant transcripts to ensure that the emerging themes were grounded in the data.

The fourth phase involved reviewing the themes for coherence and consistency. The researcher re-examined each theme to ensure that it accurately reflected the data it represented and that there was sufficient supporting evidence from across the interviews. Some codes were refined, merged, or reassigned to strengthen the internal consistency of the themes. Any redundant or weakly supported themes were dropped or modified.

In the fifth phase, themes were clearly defined and named. This involved clarifying the scope and focus of each theme and ensuring that the names captured their core essence. For example, the theme Instructional Strategies and Integration Practices was defined to include the specific ways teachers incorporated GeoGebra into their lessons, such as demonstration, student exploration, and collaborative construction tasks. Each theme was supported with illustrative quotes in the final report.

Finally, in the sixth phase, the results of the thematic analysis were written up in narrative form. This stage involved explaining each theme in detail and linking it to the research question and theoretical frameworks. Direct quotations from participants were used to substantiate the findings, and the themes were interpreted in light of the Social Constructivist Theory, Technology Acceptance Model, and relevant empirical studies.

Through this detailed process, four major themes emerged: (1) Teachers' Beliefs about GeoGebra and Mathematics Instruction, (2) Perceived Impact on Students' Learning, (3) Instructional Strategies and Integration Practices, and (4) Challenges and Support Needs. These themes provided a deeper understanding of how mathematics teachers conceptualize, implement, and experience GeoGebra in the context of geometric construction.

3.3. Discussion

3.2.1 The Effect of GeoGebra on Students' Mathematical Performance in Geometric Construction

The results revealed a statistically significant improvement in the post-test scores of students in the experimental group, who were taught using GeoGebra, compared to those taught with traditional methods. This confirms the powerful instructional potential of dynamic geometry software in improving mathematics performance.

From the lens of Cognitive Load Theory (Sweller, 1988), GeoGebra reduces extraneous cognitive load by presenting geometric concepts visually and interactively. It enables students to manipulate figures, observe real-time changes, and build intuition about constructions, thus allowing working memory to focus on intrinsic and germane learning processes.Aligned with Social Constructivist Theory (Vygotsky, 1978), GeoGebra acts as a digital scaffold within the Zone of Proximal Development (ZPD), offering interactive tools that help students actively construct mathematical meaning through teacher guidance and peer interaction. The experimental group's superior performance supports this framework, illustrating how the technology fosters collaborative and experiential learning.

Furthermore, based on the Technology Acceptance Model (TAM; Davis, 1989), when students perceive a digital tool as useful and easy to use, they are more motivated to engage deeply with it. The positive outcomes suggest students found GeoGebra intuitive and beneficial to their learning, which likely increased their willingness to interact with the material.

These findings are reinforced by Kugblenu, (2022) and Mensah (2023) who found statistically significant gains in student achievement after integrating GeoGebra into lessons on circle theorems and transformations. Adelabu et al. (2022) and Alabdulaziz et al. (2021) similarly reported improved understanding and retention among senior high students using GeoGebra. The evidence confirms that GeoGebra enhances comprehension and application in geometry topics, especially when integrated with effective pedagogy.

Teachers overwhelmingly reported that using GeoGebra had a noticeable positive impact on students' learning, particularly on engagement, comprehension, and performance during geometric construction tasks.

Teacher 1 observed that

> *"My students became more confident in class after I introduced GeoGebra. They understood constructions such as bisectors and angle duplication more quickly. Their test scores also improved."*

Teacher 4 highlighted that

> *"Students enjoy lessons more with GeoGebra. Even those who struggle with geometry can complete constructions. It keeps them motivated and interested throughout the lesson."*

Teacher 5 added that

> *"GeoGebra has helped students in my class become more independent. They try constructions on their own and even explore concepts beyond what I teach. Their performance has definitely improved."*

3.2.2 Students' Perceptions of GeoGebra in Learning Geometric Construction

Quantitative analysis of students' responses showed consistently high mean scores, indicating strong agreement that GeoGebra improved understanding, enjoyment, confidence, creativity, and performance in learning geometric construction. The Social Constructivist framework explains these positive perceptions by emphasizing that learners build knowledge best through active exploration and interaction. GeoGebra's interactive interface supports this by enabling students to construct knowledge socially and contextually, rather than through rote memorization.

Cognitive Load Theory further supports these findings. Students reported that GeoGebra made learning easier and more fun, implying that the software alleviated extraneous load while promoting germane cognitive effort. By simplifying complex constructions, the software allowed students to focus on understanding rather than procedural tasks.

Through the lens of TAM, the high levels of perceived usefulness and ease of use are evident in statements such as "GeoGebra helps me understand geometric construction better" and "I enjoy learning when GeoGebra is used." These perceptions suggest that students are more likely to adopt and benefit from the software in sustained learning environments.

This aligns with findings from Nzaramyimana et al. (2021) who reported that students viewed GeoGebra as a fun and empowering learning tool. Uwurukundo et al. (2022) and Birgin and Topuz (2021) also confirmed that student attitudes toward learning geometry improved markedly when using GeoGebra, attributing this to the software's interactive nature and the autonomy it gives learners to manipulate shapes and constructions.

Across the responses, teachers noted that GeoGebra stimulated students' curiosity and critical thinking, enabling them to construct knowledge rather than memorize procedures. The software's visualization capabilities were particularly effective in enhancing students' spatial reasoning.

Teachers reported various methods of incorporating GeoGebra into their lessons. While all used the software as a complementary tool rather than a replacement for traditional methods, they emphasized its effectiveness during demonstrations, group work, and interactive problem-solving.

Teacher 1 explained that

> *"I normally start by explaining the theory with the board, then I demonstrate using GeoGebra. Afterward, students recreate the construction using the app. This helps reinforce what I teach."*

Teacher 3 shared that

> *"I often give students exercises that involve both paper-based and GeoGebra-based constructions. They learn to compare both methods and understand the value of each."*

Teacher 2 described using GeoGebra during collaborative tasks:

> *"I create tasks where students work in pairs using GeoGebra to complete constructions. I supervise and guide their work, encouraging peer learning."*

These instructional strategies reveal that GeoGebra was employed to promote active learning, peer collaboration, and engagement through blended teaching methods.

3.2.3 Teachers' Beliefs and Instructional Practices Influencing the Effectiveness of GeoGebra

The qualitative phase revealed that while most teachers believed GeoGebra could enhance learning, their actual use of the tool varied due to factors like limited training, infrastructure challenges, and time constraints. Teachers who had received training or prior exposure to GeoGebra integrated it more effectively and more frequently than others.

According to TAM, the perceived usefulness and ease of use of GeoGebra directly influenced teachers' attitudes and behaviors. Teachers who viewed the software as pedagogically relevant and manageable were more likely to integrate it into their teaching. In contrast, those who perceived it as difficult or time-consuming expressed reluctance

From a Social Constructivist view, teachers are essential mediators in the learning process. Their beliefs and practices shape how students interact with digital tools and whether classrooms become constructivist environments. Teachers who positioned themselves as facilitators and used GeoGebra to support inquiry and discovery saw more student engagement and better outcomes.

Cognitive Load Theory also helps interpret these results. Teachers lacking training may design lessons that overload students or underuse the tool's potential, diminishing its instructional benefits. Therefore, professional development is crucial for ensuring teachers can balance cognitive load and optimize student learning through technology.

These themes resonate with Narh-Kert and Sabtiwu (2022), who emphasized the need for continuous training for effective implementation. Marange (2025) found that teachers who received integrative training materials for teaching geometry with GeoGebra expressed heightened interest and confidence in utilizing the tool effectively. Conversely, challenges such as limited professional development opportunities, inadequate technological infrastructure, and time constraints impede the effective integration of GeoGebra. Similarly, Mokotjo (2021) reported that South African high school teachers encounter challenges in integrating GeoGebra due to inadequate technological resources and support.

The data revealed that all five teachers held positive beliefs about the use of technology in mathematics instruction. Teachers generally perceived GeoGebra as a valuable tool that enhances teaching effectiveness and student understanding, particularly in geometry lessons.

Teacher 1 emphasized that

> *"technology has a major role in modern mathematics education. GeoGebra makes geometric construction more interactive and easy for students to grasp. It helps them visualize the relationships between shapes and angles better than traditional methods."*

Similarly, Teacher 2 expressed the belief that

> *"GeoGebra simplifies constructions and provides clarity. It eliminates the inaccuracies that often arise from using manual tools like compasses and rulers, and students can correct errors with ease."*

Teacher 3, although initially hesitant about digital tools, acknowledged a shift in perspective, stating that

> *"I used to think it was a distraction, but now I see that GeoGebra allows students to explore geometry more independently. They ask questions and are curious to test things on their own."*

Teachers considered GeoGebra not just a tool but a medium that transforms abstract mathematical ideas into tangible, manipulable experiences. This aligns with the constructivist view of learning, where learners build knowledge through active engagement with content.

3.2.4 Challenges and Support Needs

Despite the acknowledged benefits of GeoGebra, teachers cited several obstacles to its full integration into teaching. Key among these were infrastructure constraints, lack of digital devices, and insufficient professional development.

Teacher 1 stated that

> *"The biggest issue is access to enough devices. We also don't get formal training. I had to learn on my own, which was time-consuming."*

Teacher 4 pointed out institutional shortcomings

> *"The school does not prioritize technology integration. There's no ICT support, and the computers are outdated. Without systemic support, it's hard to sustain effective use."*

Teacher 5 emphasized student challenges as well, noting that

> *"some students haven't used GeoGebra before senior high school. We need early exposure and more training opportunities for both students and teachers."*

All five teachers recommended ongoing in-service training, reliable ICT infrastructure, and administrative support as crucial for the successful and sustained implementation of GeoGebra in mathematics classrooms.

4. Conclusions

The study concludes that the integration of GeoGebra in the teaching and learning of geometric construction significantly enhances students' mathematical performance and engagement. GeoGebra provides an interactive, student-centered learning environment that supports the visualization and manipulation of geometric figures an approach that promotes deeper conceptual understanding compared to traditional methods. These results underscore the value of digital technologies in modern mathematics instruction.

Moreover, the study highlights the critical influence of teachers' beliefs and instructional practices on the effectiveness of GeoGebra. Teachers serve as facilitators of learning; their attitudes, technological competencies, and instructional strategies determine how successfully technology is integrated into lessons. Thus, the potential of GeoGebra and educational technology in general cannot be realized without equipping teachers with the necessary skills and support.

The findings further validate the application of the Social Constructivist Theory, which emphasizes active, tool-mediated learning; the Technology Acceptance Model, which explains technology adoption based on perceived usefulness and ease of use; and the Cognitive Load Theory, which supports reducing mental overload through effective instructional design. When implemented properly, GeoGebra aligns well with all three theoretical foundations.

Based on the findings of this study, several key recommendations are made to improve the integration of GeoGebra in the teaching and learning of geometric construction. The Ghana Education Service (GES) and the Ministry of Education should organize regular professional development programs to enhance mathematics teachers' proficiency in using GeoGebra and other ICT tools. These workshops should go beyond the basic technical skills and focus on pedagogical strategies aligned with constructivist learning principles. Training sessions should expose teachers to how GeoGebra can be used to support inquiry-based, student-centered learning and provide real-time visualization of geometric concepts. Furthermore, the Ministry should review the existing ICT in Education Policy to incorporate explicit guidance on the use of dynamic mathematics software like GeoGebra in classroom instruction. At the school level, heads of senior high schools play a vital role in fostering an enabling environment for ICT integration. School leaders should encourage innovation by supporting teachers who wish to experiment with digital teaching strategies and providing them with the necessary autonomy and resources. Heads of schools should also incorporate dedicated planning time into the school schedule to allow teachers to collaborate and prepare GeoGebra-based lesson plans. This support structure will empower teachers to adopt technology with greater confidence and creativity.

Additionally, mathematics teachers must take the initiative to shift away from didactic, teacher-centered approaches toward student-centered instructional practices. Teachers are encouraged to incorporate GeoGebra into daily teaching routines to enhance visualization, promote mathematical thinking, and facilitate collaborative problem-solving. Teachers should view GeoGebra not as a supplemental tool, but as an integral part of the instructional process that can support differentiation and personalized learning.

Conflict of Interest
The authors declare no conflicts of interest.

Author contributions
All authors were involved in concept, design, collection of data, interpretation, writing, and critically revising the article. All authors approve final version of the article.

Ethical Approval
The ethics committee approved this study, as it is supervised by the Faculty supervisors for publication. No participants' names were mentioned. Informed consent was obtained from all participants involved in the study. Participants were informed of the study's purpose, procedures, and their right to withdraw at any time without any repercussions. The confidentiality and anonymity of participants were ensured throughout the research process.

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Data generated or analyzed during this study are available from the authors on request.

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