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Effects of GeoGebra-Supported Instruction on Senior High School Students' Achievement in Circle Theorem

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Abstract: *This study explored how GeoGebra-supported instruction influences Senior High School (SHS) students' achievement in circle theorem. Using a quasi-experimental design, the study employed pre-test and post-test control groups to allow for a clear comparison of learning outcomes. The participants were eighty second-year SHS students drawn from two public senior high schools in the Okaikwei North District of the Greater Accra Region, selected through systematic random sampling. Students in the experimental group were taught circle theorem concepts using GeoGebra, which allowed them to visualize and manipulate geometric ideas dynamically, while those in the control group were taught using the traditional, teacher-centred approach. Data were gathered through a geometry achievement test and analyzed using descriptive statistics and independent samples t-tests at a 5% level of significance. The results showed no statistically significant difference between the two groups in the pre-test, suggesting that the students started at comparable levels. However, a significant difference emerged in the post-test, with students in the GeoGebra group outperforming their counterparts in the control group. These findings provide clear evidence that GeoGebra-supported instruction can meaningfully improve students' understanding and achievement in circle theorem. Based on these outcomes, the study recommends that dynamic geometry software such as GeoGebra be deliberately integrated into SHS mathematics teaching to support deeper learning and improved performance.*

Keywords: GeoGebra, circle theorem, achievement, Geometry,

INTRODUCTION

Achievement in mathematics especially in geometry, continues to be a pressing challenge in Ghanaian Senior High Schools. Year after year, the West African Examinations Council (WAEC) Chief Examiners' Reports paint a similar picture: many students struggle with circle theorem, and a significant number either skip related questions entirely or attempt them unsuccessfully (WAEC Chief Examiners' Reports, 2009–2017). These recurring weaknesses suggest that the problem goes beyond students' effort alone and point instead to deeper issues in how geometric concepts are taught and understood. As a result, there has been growing concern among educators and researchers about the need for teaching approaches that move learners beyond rote procedures toward genuine conceptual understanding.

In recent years, educational technology has emerged as a promising response to this challenge. Well-designed technological tools can transform mathematics lessons by encouraging visualization, supporting logical reasoning, and actively involving learners in the learning process rather than positioning them as passive recipients of information (NCTM, 2000; Bos, 2009). Among such tools, GeoGebra stands out for its ability to seamlessly link geometry and algebra within a single, interactive environment. Through dynamic manipulation of figures, students are able to observe patterns, test conjectures, and immediately see the effects of their actions, making abstract geometric ideas more tangible and meaningful (Hohenwarter & Preiner, 2007).

Against this background, the present study set out to examine whether integrating GeoGebra into the teaching of circle theorem could lead to improved learning outcomes. Specifically, it investigated whether students exposed to GeoGebra-supported instruction would demonstrate higher achievement in circle theorem than their peers taught using the traditional, teacher-centred approach.

Hypotheses

To examine the impact of using GeoGebra compared with the traditional teaching method as instructional approaches in the teaching of circle theorems, the following hypotheses were formulated to guide the study.

1. H_1: There is a significant difference in achievement between the control group and the experimental group in the pretest.
   H_0:There is no significant difference in achievement between students taught with GeoGebra and those taught without the use of GeoGebra in posttest.

LITERATURE REVIEW

Students' Achievement in Geometry

Geometry occupies a central position in mathematics education and plays a crucial role in the development of learners' spatial reasoning, logical thinking, and problem-solving abilities. Beyond the mathematics classroom, geometric knowledge underpins learning in science, engineering, architecture, information technology, and many technical and vocational fields. For this reason, geometry is not merely a collection of shapes and theorems; it is a foundational domain through which learners develop ways of thinking that are transferable across disciplines.

Despite its importance, achievement in geometry has remained a persistent challenge for students at various levels of education. Research across different contexts suggests that many learners' experience difficulty understanding geometric concepts, applying theorems, and reasoning logically about geometric relationships (Hoffer, 1981; Van de Walle, 2001). These difficulties are often linked to the abstract nature of geometry and the manner in which it is traditionally taught. When instruction emphasizes memorization of definitions and procedures rather than conceptual understanding and exploration, students are more likely to view geometry as confusing, intimidating, and disconnected from meaningful learning.

In the Ghanaian context, concerns about students' achievement in geometry are well documented. Reports from the West African Examinations Council (WAEC) consistently highlight geometry particularly circle theorem, as one of the weakest areas in Senior High School (SHS) mathematics. Many candidates either avoid geometry questions altogether or demonstrate limited understanding when they attempt them, resulting in low scores (WAEC Chief Examiners' Reports, 2009 - 2017). Similar patterns have been observed in national and international assessments, including the West African Senior School Certificate Examination (WASSCE) and the Trends in International Mathematics and Science Study (TIMSS), where Ghanaian students continue to underperform in geometry-related items (Anamuah-Mensah & Mereku, 2005).

One major factor contributing to this situation is the continued dominance of teacher-centred instructional approaches in geometry classrooms. In many Senior High School settings, geometry lessons are largely characterized by chalk-and-talk methods, where teachers demonstrate procedures on the board while students passively copy notes and practise similar examples. Such approaches tend to emphasize rule memorisation rather than understanding and often leave little room for exploration, discussion, or visual reasoning; processes that are essential for meaningful learning in geometry (Hoffer, 1981; Van de Walle, 2001). As a result, students may be able to recall formulas or state theorems correctly, yet struggle to explain why these results hold or how they can be applied in unfamiliar or problem-solving contexts.

Another important challenge relates to students' levels of geometric thinking. The Van Hiele theory of geometric development explains that learners progress through hierarchical levels of understanding, ranging from basic visual recognition to formal deduction and rigorous reasoning (Van Hiele, 1986; Usiskin, 1982). Learning becomes ineffective when instruction is not aligned with learners' existing levels of geometric thinking. In many classrooms, SHS students are expected to work with abstract theorems and proofs even though they may still be operating at lower levels that emphasize visualization and informal reasoning. This mismatch between instructional expectations and students' cognitive readiness significantly limits understanding and contributes to persistent low achievement in geometry (Burger & Shaughnessy, 1986).

Beyond cognitive factors, affective variables such as fear, low confidence, and negative attitudes toward mathematics also play a critical role in students' performance in geometry. Research has shown that students' beliefs about mathematics strongly influence their engagement and persistence in learning tasks (Middleton & Spanias, 1999). Geometry, in particular, is often perceived as abstract, difficult, and intimidating, leading to anxiety and reduced motivation to participate actively in lessons. Over time, these negative perceptions can become self-reinforcing, causing students to disengage from learning activities and perform poorly in assessments (Hannafin & Foshay, 2008).

Given these persistent challenges, there is growing recognition of the need for instructional approaches that move beyond traditional methods and actively support students' conceptual understanding, reasoning, and engagement. Researchers and mathematics educators increasingly argue that improving achievement in geometry requires teaching strategies that emphasize visualization, exploration, and meaningful interaction with geometric ideas rather than rote learning (NCTM, 2000; Van de Walle, 2001). This shift in perspective has led to increased interest in the use of educational technology particularly dynamic geometry software, as a means of transforming how geometry is taught and learned, and of creating learning environments that are more responsive to students' cognitive and affective needs

GeoGebra and Mathematics Achievement

The integration of technology into mathematics education has been widely acknowledged as a powerful way to enhance teaching and learning, particularly in areas that require visualization and conceptual understanding. Educational technology, when used effectively, can support active learning, encourage exploration, and help students make connections between abstract concepts and concrete representations (NCTM, 2000). Within geometry education, dynamic geometry software has emerged as one of the most influential technological tools for improving students' learning experiences and achievement.

GeoGebra is a free, open-source dynamic mathematics software that integrates geometry, algebra, and graphical representations within a single interactive environment. One of its key strengths lies in its ability to allow learners to construct, manipulate, and explore geometric objects dynamically. Students can drag points, change dimensions, and immediately observe how relationships remain constant or change, thereby developing a deeper understanding of geometric properties and theorems (Hohenwarter & Jones, 2006; Preiner, 2008).

Research has consistently shown that GeoGebra-supported instruction can lead to improved achievement in mathematics. Hodanbosi (2001) reported that students who learned geometry using dynamic geometry software demonstrated significantly higher achievement than those taught using traditional construction tools. Similarly, Hannafin and Foshay (2008) found that technology-enhanced mathematics instruction promoted deeper understanding and better problem-solving performance. Ahmad Fauzi et al. (2010) also observed that students exposed to dynamic mathematical software achieved higher scores and displayed greater conceptual clarity than their peers in conventional classrooms.

One of the main reasons GeoGebra enhances achievement is its capacity to support visualization and exploration. Geometry concepts that are difficult to imagine when presented statically on a chalkboard become clearer when students can manipulate figures and observe relationships in real time. This dynamic interaction helps learners move beyond memorization to genuine understanding, enabling them to explain concepts, justify solutions, and apply knowledge flexibly.

Empirical studies conducted at the Senior High School level provide strong evidence of the effectiveness of GeoGebra. Tay and Mensah-Wonkyi (2018) found that SHS students taught mathematical theorems using GeoGebra performed significantly better than those taught using the traditional method. Their study demonstrated that GeoGebra not only improved test scores but also enhanced students' ability to reason and solve problems independently. Similar findings were reported by Chimuka (2017), who observed that learners exposed to GeoGebra-based instruction showed higher achievement and greater engagement in geometry lessons. Aydos (2015) also reported significant improvements in students' academic performance when GeoGebra was integrated into mathematics instruction.

Within the context of circle theorem, GeoGebra offers particular advantages. Circle theorems often involve relationships between angles, arcs, chords, and tangents—relationships that are difficult for students to visualize when presented as static diagrams. GeoGebra allows students to construct circles, manipulate angles, and observe invariant properties, helping them to discover and understand the underlying principles rather than simply memorizing results. As noted in Chimuka (2017), such exploratory learning experiences can directly address students' long-standing difficulties with circle theorem.

Furthermore, GeoGebra supports learner-centred and constructivist approaches to teaching. Rather than positioning students as passive recipients of information, GeoGebra encourages them to explore, make conjectures, test ideas, and refine their understanding through interaction. This shift in instructional approach aligns well with contemporary views of effective mathematics teaching, which emphasize active engagement, reasoning, and meaningful learning.

In summary, the literature provides strong evidence that GeoGebra-supported instruction positively influences students' achievement in mathematics, particularly in geometry. By promoting visualization, exploration, and conceptual understanding, GeoGebra addresses many of the cognitive and instructional challenges that contribute to poor performance in topics such as circle theorem. These findings provide a strong justification for investigating the effect of integrating GeoGebra into the teaching of circle theorem among Senior High School students, as undertaken in the present study.

METHODOLOGY

Research Design

The study adopted a quasi-experimental non-equivalent control group design, incorporating both pre-test and post-test measures to examine the effects of the instructional intervention. This design was considered appropriate because the study was conducted in real classroom settings where intact classes had to be used, making random assignment of individual students impractical. Using existing classes helped to preserve the normal teaching and learning environment and ensured that instruction was not disrupted for the sake of the research. The inclusion of a pre-test made it possible to establish the initial equivalence of the experimental and control groups before the intervention began. Similarly, the post-test provided a clear basis for comparing learning outcomes after exposure to the different teaching approaches. By comparing changes in performance across the two groups, the design allowed the study to isolate the effect of the GeoGebra-supported instruction as much as possible. Overall, the quasi-experimental approach offered a practical and methodologically sound framework for investigating the impact of the intervention within the constraints of the school context.

Population and Sample
The population for the study consisted of all second-year students from ADE Senior High School and XYZ Senior High School, both located in the Okaikwei North District of the Greater Accra Region. For ethical reasons, the names of the schools were under pseudonyms. (i.e. the actual names of the schools were not used due to ethical concerns). These schools were selected because they offered comparable learning environments and followed the same core mathematics curriculum. From this population, a sample of 80 students was drawn using systematic random sampling to ensure fairness and reduce selection bias. The use of systematic sampling helped to give every student an equal chance of being included in the study. The selected students were then organized into two groups based on their intact classes: an experimental group and a control group. Each group comprised 40 students, allowing for balanced comparison during data analysis. This sample size was considered adequate for detecting meaningful differences in learning outcomes between the two instructional approaches.

Instrumentation
A geometry achievement test focusing on circle theorem was carefully developed and used as both the pre-test and the post-test for the study. Using the same instrument at both stages made it possible to measure actual learning gains resulting from the instructional intervention rather than differences caused by test variation. The test items were drawn directly from the Senior High School Core Mathematics syllabus to ensure that they reflected the content and cognitive demands expected at that level. Particular attention was given to covering key concepts, theorems, and application-type questions related to circle geometry. To ensure validity, the instrument was reviewed by experienced mathematics educators, who examined the clarity, relevance, and difficulty level of the items. Their feedback was used to refine the questions and improve the overall quality of the test. As a result, the achievement test provided a reliable and curriculum-aligned measure of students' understanding of circle theorem.

Treatment Procedure
The experimental group was taught circle theorem using GeoGebra over a period of three weeks, during which lessons were designed to encourage exploration, visualization, and active student participation. Learners in this group interacted with dynamic constructions, manipulated diagrams, and observed geometric relationships in real time as part of the learning process. In contrast, the control group covered the same circle theorem content using the traditional teaching approach, which relied mainly on teacher explanations, board work, and worked examples. Care was taken to ensure that both groups followed the same syllabus content and learning objectives. Each group received the same amount of instructional time to eliminate any advantage that could arise from unequal exposure. This arrangement helped to ensure that any observed differences in learning outcomes could be attributed to the instructional approach rather than differences in time spent on the topic.

Data Analysis
The data collected for the study were analyzed using both descriptive and inferential statistical techniques. Mean scores and standard deviations were first computed to provide a clear picture of students' overall performance and the spread of scores within each group. These descriptive statistics made it easier to observe general trends and patterns in students' achievement before

and after the intervention. To determine whether the differences observed between the experimental and control groups were statistically meaningful, independent samples t-tests were conducted. All tests were evaluated at a 0.05 level of significance, which is commonly accepted in educational research. This combination of analytical methods allowed for a balanced and reliable interpretation of the study's findings.

RESULTS AND DISCUSSION

In testing the hypotheses, the pre-test and post-test results were carefully analyzed and compared between the experimental and control groups. This comparison made it possible to assess changes in students' performance before and after the instructional intervention. The next section therefore presents the descriptive statistics summarizing students' overall performance at both stages of the study.

Analysis of Performance of the Students Pre-Test Results

The pre-test was conducted for both the control and experimental groups one week before the treatment was administered to the experimental group. The result of the Pre-test is presented in table 1

Table 1: Pre-test results for group statistics

Group	N	Mean	Standard deviation
Experimental	40	64.3	15.34
Control	40	66.5	14.71

Table 4.1 shows that the mean score for the experimental group was 64.3 and the control was 66.5 with standard deviation of 15.34 and 14.71, respectively.

An independence t-test was used to determine whether there is a significance difference between the scores obtained by the experimental and control groups. A two tailed test was conducted at the 5 percent significance level. The result of the independent t-test is presented in table 2.

Table 2: Results of independence sample t-test for pre-test

Levene's Test frequency of variance			T – test for Equality of Means					
Scores	F	Sig.	T	DF	Sig. (2-T)	MD.	95% C.L. Lower	Upper
Equal var. assumed	0.60	0.80	-0.64	78	0.524	-2.2	-8.839	4.539
Equal var. not assumed			0.64	-77.9	0.524	-2.2	-8.840	4.540

Table 2 gives the results of Levene's test for equality of variances. This test determines whether the variance for the experimental and control groups is the same. If the Levene value is less than 0.05 then the data violate the assumption of equal variance (Pallant, 2003). However, in this study the Levene value is 0.8, which is greater than 0.05, it means equal variance is assumed. The result of the experimental group is (M = 64.3; SD = 15.34) and control group is (M = 66.5; SD = 14.71); ($t(78) = -0.64$; $p = 0.52 > .05$).

The results show that the mean value of the control was slightly above the experimental group. Analysis of the pre-test scores revealed no statistically significant difference between the experimental and control groups, indicating that both groups had comparable prior knowledge of circle theorem before the intervention.

Analysis of Performance of the Students Post-Test Results

The post test was conducted to both the control and experimental groups. Table 3 shows the group statistics results of the post-test.

Table 3: Post-test results for group statistics

Group	N	Mean	Standard deviation
Experimental	40	69.4	6.58
Control	40	54.8	11.12

Though the mean score of the experimental group was higher than the control group, we cannot conclude based on those results alone until the independence t-test is conducted.
The independent sample t-test was conducted to confirm the result obtained from the group statistics. The results of the independent sample t-test are indicated in Table 4

Table 4: Independence sample t-test for post test

Levene's Test frequency of variance			**T – test for Equality of Means**					
Scores	**F**	**Sig.**	**T**	**DF**	**Sig. (2-T)**	**MD.**	**95% C .L.**	
							Lower	**Upper**
Equal var. assumed	4.12	.046	7.15	78	0.000	14.6	10.53	18.67
Equal var. not assumed			7.15	63.33	0.000	14.6	10.52	18.68

From Table 4.4, the Levene value is 0.046 which is less than 0.05. This indicates that equal variance is not assumed. The result of the experimental group is (M = 69.4; SD = 6.58) and control group is (M = 54.8; SD = 11.12); (t (78) = 7.15; $p = .000 < .05$). From the results we reject the null hypothesis and conclude that there is a statistical significance difference in achievement between the experimental group and the control group in the post-test.

The findings of this study provide clear evidence that GeoGebra-supported instruction has a strong and positive effect on Senior High School students' achievement in circle theorem. While the pre-test results showed no statistically significant difference between the experimental and control groups, indicating that both groups had comparable prior knowledge of the topic, the post-test results revealed a marked improvement in the performance of students who were taught using GeoGebra. This improvement suggests that the observed gains were not due to chance or pre-existing differences between the groups, but rather to the instructional approach adopted during the intervention.

Students in the experimental group outperformed their counterparts in the control group by a considerable margin in the post-test. This difference highlights the instructional value of

GeoGebra, particularly its ability to support meaningful learning through dynamic visualization and interaction. Instead of passively memorizing circle theorems and procedures, students were able to manipulate geometric figures, observe invariant relationships, and test ideas in real time. Such experiences appear to have helped learners develop a clearer and more connected understanding of circle geometry, which translated into improved performance in the achievement tests.

In contrast, students in the control group, who were taught using the traditional method, showed comparatively lower gains. This outcome reinforces long-standing concerns that teacher-centred approaches, which rely heavily on explanation and board work, may not adequately support students' understanding of abstract geometric concepts. Without opportunities for exploration and visual reasoning, students may remember rules temporarily but struggle to apply them accurately in problem-solving situations. The results of this study therefore suggest that traditional methods alone may be insufficient for addressing persistent learning difficulties in circle theorem.

The findings of this study are consistent with earlier research on the use of dynamic geometry software in mathematics education. Hodanbosi (2001) reported that students exposed to dynamic geometry environments achieved significantly higher scores than those taught using conventional approaches. Similarly, Chimuka (2017) found that GeoGebra-enhanced instruction improved learners' understanding and achievement in geometry, while Tay and Mensah-Wonkyi (2018) reported significant gains among SHS students taught mathematical theorems using GeoGebra. The agreement between the present findings and those of previous studies strengthens the evidence base supporting the effectiveness of GeoGebra as a teaching and learning tool in geometry.

Beyond achievement, the results of this study also align closely with the principles of constructivist learning theory, which emphasizes active learner involvement in the construction of knowledge. GeoGebra creates a learning environment in which students are not mere recipients of information but active participants who explore, experiment, and make sense of mathematical ideas through interaction. By engaging students cognitively and visually, GeoGebra supports deeper conceptual understanding, which is essential for long-term retention and transfer of knowledge.

Overall, the findings suggest that integrating GeoGebra into the teaching of circle theorem can significantly enhance students' learning outcomes. The use of dynamic geometry software not only improves achievement but also addresses some of the fundamental challenges associated with teaching and learning geometry at the Senior High School level. These results underscore the need for mathematics educators to embrace technology-supported instructional approaches that promote understanding, reasoning, and active engagement, rather than relying solely on traditional teaching methods.

CONCLUSION AND RECOMMENDATIONS

The findings of this study clearly indicate that integrating GeoGebra into the teaching of circle theorem has a meaningful and positive impact on Senior High School students' achievement.

Compared to the traditional instructional approach, GeoGebra-supported instruction enabled students to better visualize geometric relationships and develop a deeper understanding of abstract concepts. By allowing learners to explore, manipulate, and test ideas dynamically, GeoGebra moved learning beyond memorization and supported more meaningful and lasting understanding. Overall, the study demonstrates that technology-enhanced instruction, when used purposefully, can significantly improve learning outcomes in geometry.

Based on these findings, the study makes the following recommendations:

1. GeoGebra should be deliberately integrated into Senior High School mathematics instruction, particularly in the teaching of geometry topics such as circle theorem, where visualization and conceptual understanding are essential.
2. Mathematics teachers should be provided with regular training and professional development opportunities to build their confidence and competence in using GeoGebra effectively in the classroom.
3. Curriculum developers and educational policymakers should consider embedding the use of dynamic geometry software into the SHS mathematics curriculum to support innovative and learner-centred teaching practices.

These steps would help ensure that the benefits of GeoGebra are fully realized in mathematics classrooms and contribute to improved student performance and engagement.

Future Research

Since GeoGebra plays an active role in facilitating students' understanding of the circle theorem, it is necessary to explore other teaching methodologies. In view of GeoGebra's role, a future study must thoroughly investigate how different GeoGebra-integrated pedagogies, for instance, student-led exploration versus teacher-led demonstration, compare in effectiveness.

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