

Research Article

Optimizing Senior High School Students' Achievement in Geometric Transformations through GeoGebra Integration: A SAMR Model Approach

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Abstract: This study examined the effect of GeoGebra integration on Senior High School students' achievement in geometric transformations using the SAMR model as a framework for technology integration. A concurrent mixed-methods design was employed involving 200 second-year students from two government-assisted senior high schools in the Obuasi East and West Districts of the Ashanti Region of Ghana. The experimental group was taught using GeoGebra, while the control group received conventional instruction. Data were collected through a Geometry Achievement Test (GAT) and semi-structured interviews. Quantitative data were analyzed using descriptive statistics and independent samples t-tests, while qualitative data were analyzed thematically. The pre-test results revealed no significant difference between the two groups ($t = 0.285$, $p = 0.82$), indicating similar prior knowledge. However, post-test findings showed that the experimental group significantly outperformed the control group ($M = 9.00$; $M = 5.00$, $p = 0.011$). Students also reported that GeoGebra enhanced engagement, motivation, collaboration, and conceptual understanding, particularly at the higher levels of the SAMR model. The study concludes that GeoGebra integration significantly improves students' achievement and learning experiences in geometric transformations. It is recommended that mathematics teachers integrate GeoGebra into instruction to promote effective and engaging mathematics learning.

Keywords: GeoGebra, geometric transformations, SAMR model, mathematics achievement, technology integration, student engagement

1. Introduction

In the realm of Senior High School mathematics education, the effective teaching and learning of geometric transformations are crucial for students' spatial reasoning and problem-solving skills (Xu et al., 2025). Geometric transformation topics, such as translations, rotations, reflections, and dilations, are essential components of the curriculum (González-Campos et al., 2022). To enhance students' understanding and achievement in these geometric concepts, the integration of technology has emerged as a promising approach (Pujijanto, 2024). One such technology that has gained popularity in mathematics classrooms is GeoGebra. It is a dynamic mathematics software that combines geometry, algebra, and calculus in an interactive platform (Sebsibe & Abdella, 2025). It allows students to visualize mathematical concepts, explore relationships, and solve problems graphically and analytically (Gurmu et al., 2024). The software's versatility and user-friendly interface make it an attractive option for educators seeking to incorporate technology in mathematics instruction (Batiibwe, 2024; Sebsibe & Abdella, 2025).

The traditional approach to teaching mathematics often involves static representations of concepts, leading to limited engagement and abstraction for many students. In contrast, GeoGebra's dynamic features enable students to manipulate geometric figures, algebraic expressions, and functions, fostering a deeper understanding of mathematical relationships. Research has shown that GeoGebra integration in mathematics classrooms can improve students' problem-solving skills, conceptual understanding, and overall motivation for the subject (Drijvers et al., 2010; Uwurukundo et al., 2020; Munyaruhengeri et al., 2025). The substitution, augmentation, modification, redefinition (SAMR) model offers a robust

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framework to understand the integration of technology in educational settings. The model categorizes technology integration into four levels, starting from simple substitution to transformative redefinition. By applying the SAMR model to GeoGebra integration, this study seeks to examine how the software progresses from being used as a direct substitute for traditional methods to fundamentally transforming the way mathematics is taught and learned. Furthermore, the SAMR model offers a systematic framework to assess how GeoGebra is integrated into the teaching and learning process. While initial applications may involve simple substitution, more transformative uses of GeoGebra can redefine mathematics learning experiences, enabling students to collaboratively explore mathematical phenomena and develop critical thinking skills (Wassie & Zergaw, 2019).

The SAMR model offers a relevant framework for examining the impact of GeoGebra on mathematics learning. The model categorizes technology integration into four levels, each representing a different degree of transformation in instructional practices. Substitution and Augmentation refer to technology use as a direct substitute or enhancement of traditional methods, respectively. Modification and Redefinition, on the other hand, represent more transformative uses of technology that lead to significant changes in teaching and learning approaches (Foulger et al., 2017; Liu et al., 2024).

Understanding how GeoGebra aligns with the SAMR model can provide valuable insights into the depth of technology integration in mathematics classrooms. By exploring the progression of GeoGebra's use from substitution to redefinition, educators can gain a better understanding of how to optimize its integration for enhanced learning outcomes. Moreover, investigating the impact of GeoGebra on students' conceptual understanding and problem-solving abilities can inform best practices for technology-enhanced mathematics instruction (Mensah et al., 2023).

The integration of GeoGebra, a dynamic mathematics software, in mathematics education has shown promise in enhancing students' conceptual understanding and problem-solving skills. At the same time, the SAMR model categorizes technology integration into four levels based on the degree of transformation in instructional practices (Jude et al., 2014). Understanding the extent to which GeoGebra is integrated at each SAMR level can provide insights into the depth of technology use in mathematics classrooms and its potential impact on learning outcomes.

Previous research (Romrell et al., 2014; Belgheis & Kamalludeen, 2018) has suggested that GeoGebra can enhance students' conceptual understanding and problem-solving skills. However, a comprehensive analysis that examines these improvements compared to traditional methods is necessary to establish the efficacy of GeoGebra as a tool for enhancing mathematics learning. In addition, little research has systematically investigated the extent to which GeoGebra's integration aligns with the SAMR model for ICT integration and how different levels of integration influence students' learning experiences in mathematics classrooms (Lotey et al., 2025). Therefore, this study aims to explore the effect of GeoGebra in enhancing mathematics learning using the SAMR model as the guiding framework.

The purpose of this study is to explore the effect of GeoGebra integration in enhancing mathematics learning and to examine how this integration aligns with the SAMR model for ICT integration. The study aims to investigate the impact of GeoGebra at different levels of integration on students' conceptual understanding, problem-solving abilities, and attitudes towards mathematics learning. To address the aim of the study, the research was guided by the following research questions, which focus on the key dimensions of the problem under investigation: (1) How does the use of GeoGebra in geometric transformation instruction impact students' achievement in comparison to traditional methods? (2) How do students perceive the learning experience and engagement when utilizing GeoGebra for geometric transformations at different SAMR levels?

3. Literature Review

The SAMR model categorizes technology integration into four levels, each representing a different degree of transformation in instructional practices, where substitution means that technology is used as a direct substitute for traditional teaching methods without significant changes in the learning task or process (Batiibwe, 2024). Augmentation suggests that technology is used to enhance the learning experience, providing improvements in specific aspects

of the task. At the same time, modification says that technology allows for significant redesign of learning tasks, enabling new possibilities and approaches not possible without technology (Olsson, 2019). And redefinition is used to show that technology enables the creation of new and transformative learning experiences that were previously inconceivable without technology, fundamentally changing the nature of the task.

By adopting the SAMR model as the theoretical framework, this study will analyze the level of GeoGebra integration in teaching geometric transformations and explore how the use of GeoGebra progresses from simple substitution to transformative redefinition. This framework will guide the investigation into the impact of technology integration on students' achievement and engagement, as well as teachers' perspectives on incorporating GeoGebra into their instructional practices.

The conceptual framework explores the impact of GeoGebra integration on students' achievement and teachers' perspectives in the context of teaching geometric transformations. It examines how the use of GeoGebra aligns with the SAMR model and how this alignment affects students' learning experiences and outcomes. The framework also considers the role of teachers' experiences in shaping effective GeoGebra integration (figure 1).

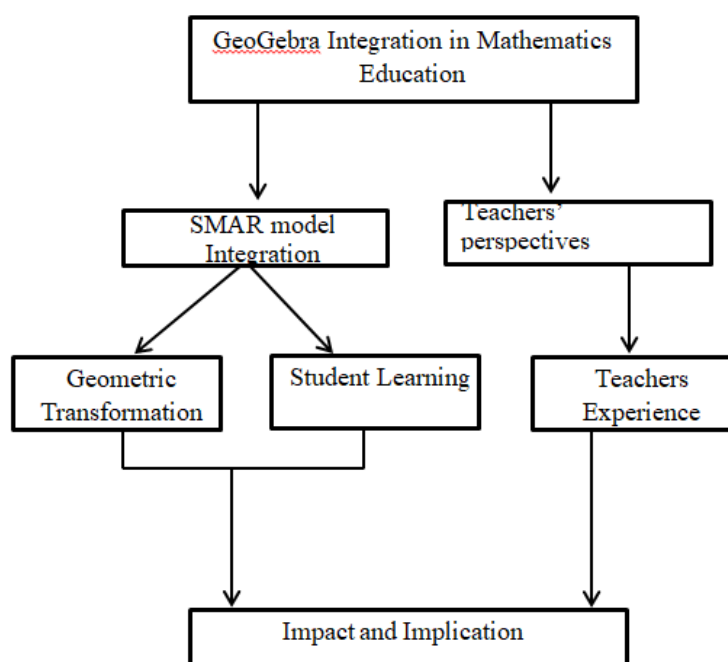


Figure 1. Developed conceptual framework.

The central component of the conceptual framework is the integration of GeoGebra, a dynamic mathematics software application, into the teaching and learning of geometric transformations in mathematics classrooms. GeoGebra serves as the primary instructional innovation that facilitates interactive visualization, exploration, and manipulation of geometric concepts (Majerek, 2014). Its integration is conceptualized through the SAMR model, which illustrates the progressive levels of technology adoption in instructional practice. At the substitution level, GeoGebra replaces traditional instructional tools with minimal functional change. At the augmentation level, it enhances teaching through additional features that improve learning efficiency.

At the modification level, GeoGebra enables significant redesign of instructional activities, while at the redefinition level, it supports the creation of innovative learning experiences that would be difficult or impossible to achieve using conventional teaching methods. The framework also incorporates teachers' perceptions of GeoGebra integration, including their attitudes, beliefs, confidence, and prior experiences with the software. These perceptions play a critical role in determining the extent to which GeoGebra is effectively adopted and utilized in classroom instruction. Positive teacher perceptions are expected to promote meaningful integration, whereas negative perceptions may hinder successful implementation. The

instructional focus of the framework is geometric transformations, specifically the teaching and learning of translations, rotations, reflections, and enlargements. GeoGebra provides a dynamic environment that enables learners to visualize and manipulate these transformations in real time, thereby fostering conceptual understanding, mathematical reasoning, and active engagement with geometric concepts.

GeoGebra is a dynamic mathematics software package that integrates geometry, algebra, calculus, statistics, and graphing capabilities into a single interactive platform. GeoGebra has become one of the most widely used digital tools in mathematics education because of its versatility, accessibility, and interactive learning environment (Hohenwarter et al., 2010). The software enables learners and teachers to explore mathematical concepts dynamically, making it particularly valuable for enhancing mathematics teaching and learning. This section reviews the literature on the educational potential of GeoGebra, with emphasis on its features, instructional applications, and contribution to students' mathematical learning.

One of GeoGebra's distinctive features is its seamless integration of geometric and algebraic representations. The software enables users to construct geometric figures while simultaneously displaying the corresponding algebraic expressions, thereby strengthening learners' understanding of the relationship between visual and symbolic representations of mathematics (Ruru et al., 2024). This dual representation allows teachers to present abstract mathematical concepts in a visual, dynamic, and interactive manner, making mathematical ideas more accessible and meaningful to students.

Another major strength of GeoGebra is its interactive learning environment, which promotes active student engagement throughout the learning process. Students can manipulate geometric objects, graphs, and mathematical functions in real time, allowing them to investigate mathematical properties, visualize transformations, and explore relationships among mathematical concepts (Thapa et al., 2022). Such interactivity shifts students from passive recipients of information to active participants in knowledge construction, thereby fostering deeper conceptual understanding and greater motivation to learn mathematics.

The visualization capabilities of GeoGebra play a significant role in facilitating conceptual understanding. Studies have demonstrated that the software's dynamic visual representations improve students' comprehension and retention of abstract mathematical concepts by enabling them to observe mathematical relationships as they evolve (Durmuş & Karakirik, 2006). For example, learners can easily visualize geometric transformations such as translations, rotations, reflections, and enlargements, thereby bridging the gap between concrete experiences and abstract mathematical reasoning. These visual experiences contribute to the development of conceptual understanding, spatial reasoning, and mathematical problem-solving skills.

GeoGebra also provides an exploratory learning environment that encourages inquiry and discovery. Rather than merely following procedural steps, students are able to investigate mathematical situations, formulate conjectures, test hypotheses, and identify patterns independently. This discovery-oriented approach promotes learner autonomy, critical thinking, and meaningful engagement with mathematical concepts (Lee & Zakaria, 2012). Through guided exploration, students gain a deeper appreciation of mathematical structures and the interconnectedness of mathematical ideas.

Furthermore, GeoGebra's flexibility and adaptability make it suitable for learners across different educational levels and ability groups. Teachers can design customized instructional activities that accommodate diverse learning styles, varying levels of prior knowledge, and individual learning needs (Hohenwarter et al., 2010). This capacity to support differentiated instruction enhances inclusivity in mathematics classrooms by ensuring that all learners have opportunities to engage with mathematical concepts at an appropriate pace and level of complexity.

Several empirical studies have examined the effectiveness of GeoGebra in improving the teaching and learning of geometric transformations. Overall, the findings consistently indicate that integrating GeoGebra into mathematics instruction enhances students' academic achievement, conceptual understanding, and problem-solving skills. For example, Hilton (2016) reported that students who received GeoGebra-based instruction achieved significantly higher scores in geometric transformations than those taught using conventional teaching methods. Similarly, Graven and Heyd-Metzuyanim (2019) found that the use of

GeoGebra promoted deeper conceptual understanding and improved students' ability to solve problems involving geometric transformations. These findings suggest that GeoGebra provides an effective instructional environment for facilitating meaningful learning in geometry.

One of the primary educational benefits of GeoGebra is its ability to enhance visualization and conceptual understanding. The software enables students to interact dynamically with geometric figures by performing transformations such as translations, rotations, reflections, and enlargements while immediately observing the resulting changes (Durmuş & Karakirik, 2006). This immediate visual feedback helps learners connect abstract mathematical concepts with concrete visual experiences, thereby reducing misconceptions and strengthening conceptual understanding. By making geometric transformations visible and interactive, GeoGebra supports the development of students' spatial reasoning and geometric thinking.

GeoGebra also promotes active student engagement through its interactive learning environment. Rather than passively observing teacher demonstrations, students actively manipulate geometric objects, investigate transformation properties, and explore mathematical relationships independently (Dockendorff & Solar, 2018). This inquiry-oriented approach encourages learners to construct knowledge through exploration and experimentation, fostering greater ownership of learning and increasing students' confidence in understanding geometric concepts.

Another important advantage of GeoGebra is its capacity to support differentiated and personalized instruction. Because the software is highly adaptable, teachers can design learning activities that accommodate varying levels of student ability, prior knowledge, and learning preferences (Hohenwarter et al., 2010). Activities can be modified in complexity, allowing both high-achieving and struggling learners to engage with mathematical content at an appropriate level. Consequently, GeoGebra contributes to more inclusive mathematics classrooms where diverse learners are provided with equitable opportunities for success.

In addition, GeoGebra provides an effective platform for developing students' problem-solving and critical thinking skills. The software enables learners to investigate geometric properties, formulate conjectures, test hypotheses, and verify mathematical relationships within a dynamic environment (Mukamba & Makamure, 2020). Such exploratory learning experiences encourage analytical reasoning and help students develop a deeper understanding of the underlying principles governing geometric transformations. These higher-order thinking skills are essential for meaningful mathematical learning and long-term academic success.

Research has also demonstrated that learning geometric transformations with GeoGebra improves students' retention and transfer of knowledge. According to Uwurukundo et al. (2020), the combination of dynamic visualization and interactive exploration reinforces students' understanding of transformation concepts, enabling them to retain knowledge more effectively and apply it to unfamiliar mathematical problems and real-world contexts. This suggests that GeoGebra not only enhances immediate learning outcomes but also supports the long-term development of mathematical competence.

Finally, GeoGebra has been shown to foster positive attitudes toward mathematics. Its interactive and visually engaging environment makes mathematics more enjoyable and less intimidating for many learners. Oktiningrum et al. (2016) reported that students generally perceived GeoGebra as a useful instructional tool that increased their interest, motivation, and confidence in learning mathematics. Positive learning experiences generated through GeoGebra are therefore likely to enhance students' willingness to participate actively in mathematics lessons and sustain their engagement with geometric transformations over time.

The SAMR model provides a widely recognized framework for understanding the levels of technology integration in educational settings. The model categorizes technology use into four progressive stages: substitution, augmentation, modification, and redefinition, representing a continuum from technology as a direct replacement for traditional instructional tools to technology as a catalyst for transforming learning experiences. Within mathematics education, the SAMR model has been employed to examine how digital technologies such as GeoGebra can enhance teaching and learning beyond merely replacing conventional instructional methods.

Applying the SAMR framework to mathematics instruction, Tunjera and Chigona (2020) demonstrated that the integration of GeoGebra can progress from simple substitution of

traditional teaching resources to the redefinition of classroom learning activities. Their study emphasized that while GeoGebra is often initially used to replace chalk-and-board demonstrations, its greatest educational value is realized when teachers employ it to design innovative learning experiences that encourage collaboration, inquiry, and conceptual exploration. The authors argued that transformative integration enables students to engage with mathematical concepts in ways that would be difficult to achieve using traditional instructional approaches alone.

Students' perceptions of learning with GeoGebra have generally been positive across numerous studies. Uwurukundo et al. (2020) found that students appreciated the software's interactive features and dynamic visual representations, which increased their engagement, motivation, and participation during geometry lessons. Students further reported that GeoGebra enhanced their understanding of geometric transformation concepts by enabling them to visualize and manipulate geometric objects in real time. These findings suggest that GeoGebra contributes to a more meaningful and enjoyable learning experience, thereby improving students' conceptual understanding of geometry.

Teachers play a central role in the successful implementation of GeoGebra in mathematics classrooms. Hensberry et al. (2015) examined teachers' perspectives on integrating GeoGebra into geometry instruction and concluded that the software has considerable potential to improve students' understanding of geometric transformations. However, the study also emphasized that effective implementation depends largely on teachers' pedagogical competence, technological knowledge, and access to continuous professional development. Adequate training and institutional support were identified as essential factors in maximizing the instructional benefits of GeoGebra.

Research further indicates that many mathematics teachers perceive GeoGebra as a valuable instructional resource because of its capacity to enhance visualization and facilitate conceptual understanding. According to Jupri and Drijvers (2016), teachers value GeoGebra's ability to dynamically represent mathematical concepts and enable learners to observe relationships between geometric transformations and their corresponding algebraic representations. These dynamic visualizations help simplify abstract mathematical ideas, making them easier for students to understand while promoting meaningful conceptual learning.

GeoGebra also supports the adoption of learner-centered and inquiry-based instructional strategies. Rather than relying solely on teacher demonstrations, educators can use the software to design exploratory activities that encourage students to investigate mathematical relationships, formulate conjectures, and discover geometric properties independently (Jupri & Drijvers, 2016). Such instructional practices promote active participation, collaborative learning, and the development of higher-order thinking skills, including critical thinking, reasoning, and mathematical problem solving.

Despite these educational benefits, several challenges continue to hinder the effective integration of GeoGebra into mathematics instruction. Akkaya et al. (2015) identified limited access to technological resources, inadequate instructional time, insufficient teacher training, and difficulties aligning GeoGebra activities with prescribed curricula as major barriers to implementation. These constraints may discourage teachers from incorporating the software into regular classroom practice despite recognizing its instructional value.

Another commonly reported challenge is the learning curve associated with mastering GeoGebra's features and instructional applications. Akcay (2017) observed that teachers, particularly those with limited experience in educational technology, often require substantial time and effort to become proficient in using the software effectively. Although this initial adjustment period may present difficulties, increased familiarity with GeoGebra enables teachers to utilize its full range of interactive features to enhance mathematics instruction.

To overcome these challenges, researchers consistently emphasize the importance of sustained professional development and collaborative learning communities. Professional training programs can strengthen teachers' technological, pedagogical, and content knowledge while building confidence in integrating GeoGebra into classroom practice. Furthermore, collaboration among teachers provides opportunities to exchange instructional resources, share successful classroom experiences, and develop effective teaching strategies for using GeoGebra (Jupri & Drijvers, 2016). Such collaborative and institutional support is

essential for promoting the effective and sustainable integration of GeoGebra in mathematics education.

3. Materials and Methods

The study will employ a concurrent mixed-methods design, where data collection and analysis will occur concurrently. Both quantitative and qualitative data will be collected at the same time, and the findings will be integrated to provide a comprehensive understanding of the impact of GeoGebra integration on geometric transformations in mathematics education. The quantitative component of the study will involve collecting numerical data to measure the impact of GeoGebra integration on students' achievement in geometric transformations. This data was obtained through pre-test and post-tests to compare students' performance before and after the GeoGebra intervention. The qualitative data was collected through interviews to explore students' learning experiences, perceptions, and engagement with GeoGebra. The quasi-experiment procedure is presented below (table 1).

Table 1. Procedure for the quasi-experiment.

Group	Pre-test	Treatment	Post-test
A	Q ₁	X	Q ₂
B	Q ₁	C	Q ₂

In the study, a pre-test (Q₁) was conducted for both the experimental (A) and control (B) groups to assess the initial proficiency level of participants before any intervention. The experimental group received ICT integrated lessons (X), where GeoGebra was integrated into the teaching of geometric transformations. In contrast, the control group underwent traditional instruction (C) without the use of GeoGebra. Following the intervention, a post-test (Q₂) was administered to both groups to measure the students' achievement resulting from the different teaching methods.

The study was conducted in the Obuasi West and East districts in the Ashanti Region of Ghana. The participants consisted of all second-year students enrolled in the 2025/2026 academic year in two government-assisted Senior High Schools (SHSs) within the districts. These schools, coded as School A and School B, were purposively selected based on their similar status and academic achievement for the study. In Ghana, students are admitted to SHSs through the Computerized School Selection Placement System (CSSPS), and this process is followed in the selected schools as well. The students in these schools, like in many other SHSs across the country, predominantly come from low socio-economic backgrounds and have lower entry grades due to their status as less endowed schools.

The population for this study consists of all second-year (students enrolled in schools A and B within the Obuasi West and East districts in the Ashanti Region of Ghana for the 2025/2026 academic year. Schools A and B are government-assisted senior high schools in the districts. Systematic random sampling technique was used to select one hundred (100) participants from each school, resulting in a total of two hundred (200) participants. The participants were assigned to two groups: the Experimental group from School A and the Control group from School B. This sampling technique ensured that the required number of participants was selected from the sample in a systematic manner without disrupting the contact hours of the students. The systematic sampling technique enabled the researchers to select samples from each class using their class registers or lists, ensuring that the selected students were representative of the population of each school (Descombe, 2010).

Table 2 provides information on the samples selected from different academic programs and streams in School A. The school offers six academic programs: Science, General Arts, Visual Art, Home Economics, Business, and Technical. Each program has a varying number of streams, and the total number of students enrolled in all streams is 1026. From this population, a total of 100 students were selected as the sample for the study. For instance, in the Science program, there are five streams with 259 students in total. From this program, 19 students were selected as part of the sample. Similarly, the process was followed for each academic program, and the total number of selected students adds up to 100.

Table 2. Samples from academic programs and streams in School A.

Program of study	Number of streams	Number of students	Number selected
Science	5	259	19
General arts	4	220	18
Visual art	2	100	15
Home economics	2	114	16
Business	1	48	12
Technical	6	285	20
Total	20		

Table 3 presents the same information for School B, which also offers five academic programs: Science, General Arts, Visual Art, Home Economics, and Business. The total number of students in all streams is 871, from which a total of 100 students were systematically selected as the sample for the study. These tables show the distribution of the selected sample from each academic program and stream in both School A and School B, providing a representative sample for the study.

Table 3. Samples from academic programs and streams in School B.

Program of study	Number of streams	Number of students	Number selected
Science	3	187	25
General arts	5	280	28
Visual art	2	123	19
Home economics	3	176	17
Business	2	105	11
Total	15		

This study employed two data collection methods, namely the Geometry Achievement Test (GAT) and a semi-structured interview guide, to gather data from the participants. The GAT was used as a quantitative tool to measure the level of participants' attainment in geometric transformation over the study period. This test was designed based on the transformation to align with the Ghanaian mathematics curriculum objectives. The GAT comprised two versions, one administered as a pre-test and the other as a post-test, to eliminate potential bias in the scores. Both versions measured the same construct and consisted of two sections: Section A with ten (10) multiple-choice items, and Section B with two (2) subjective questions of greater difficulty. The items in the GAT assessed the two profile dimensions of Knowledge and Understanding (KU) and Application of Knowledge (AK) related to geometric transformations. The GAT has been widely used in previous mathematics research to measure students' attainment in geometry (Hidayatullah & Csikos, 2024; Awoniyi & Butakor, 2021). Table 4 shows the structure of the GAT for both the pre-test and post-test.

Table 4. Domains of the test items.

Objectives	Number of items /profile dimension	
	Multiple choice (KU)	Subjective (AK)
Reflection	3	1
Translation	2	0
Rotation	3	1
Enlargement	2	0
Total	10	2

The researchers used a semi-structured interview guide to gather qualitative data from the participants. The interview guide contained open-ended questions designed to explore the views of participants who were taught with GeoGebra on how this method motivated them to study during the treatment period. The questions encouraged participants to provide in-depth responses about the motivational benefits of ICT integration, particularly GeoGebra instruction. The interview questions included inquiries about the differences participants

noticed in their learning process with ICT integration compared to traditional teaching methods, how PowerPoint instruction motivated them to study mathematics, and their preference for continued use of ICT integration in mathematics education. Semi-structured interviews were chosen as they allowed for in-depth conversations and generated qualitative data through open-ended questions (McLeod & Elliott, 2011). The combination of the GAT and the semi-structured interview guide enabled the researchers to gather both quantitative and qualitative data to comprehensively understand the impact of GeoGebra integration on students' achievement in geometric transformations and their perspectives on the motivational benefits of ICT integration in mathematics education.

The construction of the GAT was based on consultation with experts in the field of mathematics education, including three lecturers from the Department of Mathematics Education at Appiah Minkah University of Skills Training and Entrepreneurial Development, two PhD students in Mathematics Education from AAMUSTED, and two Ghana Education Service (GES) SHS mathematics teachers. The SHS mathematics syllabus and approved textbooks by GES were also consulted to ensure that the test items accurately assessed the intended learning outcomes in geometric transformations. Pilot Testing: The GAT was pilot-tested on 20 students selected from a similar school in the different district. This pilot test helped detect any lack of clarity in the phrasing of the questions and provided insights into the appropriateness of the time needed for test completion.

To assess the reliability of the GAT, the researchers employed a parallel forms reliability test approach. Two versions of the test, one as a pre-test and the other as a post-test, were administered to the same intact SHS 2 class of 50 students in one of the selected schools. Participants' responses for both versions of the GAT were scored and correlated using the Pearson correlation coefficient (r) in SPSS. The obtained r value of 0.843 indicates a good degree of reliability for the GAT.

The semi-structured interview guide was reviewed and verified by the second researcher, who is a senior lecturer in the Department of Mathematics at AAMUSTED. This review ensured that the interview questions were appropriate and aligned with the research objectives.

During three weeks, both the experimental and control groups participated in four lessons focusing on geometric transformation. The teaching methods for the two groups differed significantly. The control group experienced traditional teaching practices, where marker boards and textbook examples were used in the instructional process. On the other hand, the experimental group received an innovative approach through ICT integration, specifically using GeoGebra, a dynamic mathematics software. The experimental group's GeoGebra lessons were thoughtfully prepared and de-signed based on the principles of the SAMR model. It facilitated the integration of GeoGebra into the teaching and learning process, aiming to enhance the students' engagement and the overall learning experience.

The data collected for this study encompassed both quantitative and qualitative data. The quantitative data, obtained from the GAT scores, underwent analysis using Statistical Package for Social Sciences (SPSS) version 21.0. Descriptive statistics, such as measures of central tendencies (mean, median, and mode) and measures of dispersion (standard deviation and range), were employed to gain insights into the distribution and variation of the scores. Additionally, inferential statistics, specifically independent samples t-test, were conducted to compare and identify any significant differences in the scores between the experimental and control groups. The significance level for the t-test was set at 95% confidence level. On the other hand, the qualitative data collected from one-on-one interviews was analyzed using thematic analysis. The recorded audio from the interviews, conducted with participants based on the interview guide's topical areas, served as the primary data source. Thematic analysis involved identifying recurring themes, patterns, and meanings within the interview data. The researcher carefully examined the recorded audios, transcribed the content, and systematically coded the data based on emerging themes. The outcomes of the thematic analysis were interpreted, providing valuable insights into the participants' perspectives and experiences with the GeoGebra integration and its impact on their motivation and learning in geometric transformation.

4. Results

4.1. Impact of the use of GeoGebra in geometric transformation instruction upon students

A pre-test was administered to the two groups (control group and experimental group) one week before the intervention in order to check whether the two groups were comparable in terms of their performance before the intervention. Table 4 shows the descriptive statistics for the pre-test results for the two groups.

From the table 5 the Control group ($N = 100$) exhibited a mean pre-test score of $M = 4.82$ ($SD = 1.70$). The range of scores within this group varied from a minimum of 1.00 to a maximum of 7.00. The Experimental group ($N = 100$) displayed a mean pre-test score of $M = 4.63$ ($SD = 1.28$). The range of scores within this group ranged from a minimum of 2.00 to a maximum of 6.00. The results revealed that the Control group had a slightly higher mean pre-test score ($M = 4.82$) compared to the Experimental group ($M = 4.63$). However, this difference in means is not substantial. Additionally, the standard deviation for the Control group ($SD = 1.70$) is higher than that of the Experimental group ($SD = 1.28$), indicating greater variability in pre-test scores in the Control group compared to the Experimental group. While the Control group had a wider range of scores (ranging from 1.00 to 7.00), the Experimental group's range was narrower (ranging from 2.00 to 6.00).

Table 5. Descriptive statistics for the pre-test results.

Groups	Number	Mean	Standard deviation	Max. value	Min value
Control	100	4.82	1.70	7.00	1.00
Experimental	100	4.63	1.28	6.00	2.00

According to the table 6, the Control group ($N = 100$) exhibited a mean pre-test score of ($M = 4.82$, $SD = 1.70$). The Experimental group ($N = 100$) displayed a mean pre-test score of ($M = 4.63$ ($SD = 1.28$)). The calculated t-value for the comparison was $t = 0.285$, with 198 degrees of freedom. The associated p-value was $p = 0.82$. The results of the Independent Samples T-test revealed that there was no statistically significant difference between the Control and Experimental groups in terms of their pre-test scores ($t = 0.285$, $p = 0.82$). This indicates that, at the outset of the study, the two groups did not display significantly different levels of performance on the pre-test measure.

Table 6. Independent samples t-test of pre-test results.

Group	N	Mean	Std.Dev.	t- value	df	P –value
Control group	100	4.82	1.70	0.285	198	0.82
Experimental group	100	4.63	1.28			

From the table 7, the Control group, consisting of 100 samples, has a mean value of 5.34. The wide standard deviation of 3.70 suggests considerable variability in the data points around the mean. The highest score observed in this group is 7.00, while the lowest is 1.00. Experimental group, also comprising 100 samples, has a substantially higher mean of 9.12. The lower standard deviation of 1.52 indicates that the data points in this group are less spread out from the mean compared to the control group. The highest score achieved in the Experimental group is 10.00, and the lowest is 6.00. Comparing the mean values, it's evident that the experimental group has a significantly higher mean (9.12) compared to the control group's mean (5.34). This suggests that, on average, the experimental group achieved higher scores in this metric compared to the control group.

Table 7. Group statistics of post-test results.

Groups	Number	Mean	Standard deviation	Max. value	Min value
Control	100	5.34	3.70	7.00	1.00
Experimental	100	9.12	1.52	10.00	6.00

Table 8 shows that the GeoGebra treatment group ($N = 100$) exhibited a mean outcome measure score of $M = 9.00$ ($SD = 2.70$). The calculated t-value for this group was $t = 0.041$, with 198 degrees of freedom. The associated p-value was $p = 0.011$. The Conventional treatment group ($N = 100$) demonstrated a mean outcome measure score of $M = 5.00$ ($SD = 4.28$). However, the t-value and p-value for this group were not specified. The results

indicated that, the GeoGebra treatment led to a mean outcome measure score of 9.00, while the Conventional treatment resulted in a mean score of 5.00. The calculated t-value of 0.041 for the GeoGebra group, along with a p-value of 0.011, suggests a statistically significant effect of the GeoGebra treatment on the outcome measure scores.

Table 8. Independent sample t-test of post-test score.

Treatment	N	Mean	Std.Dev.	t-value	Df	P-value
GeoGebra	100	9.00	2.70	0.041	198	0.011
Conventional	100	5.00	4.28			

4.2. Students' perceptions of the learning experience and engagement through GeoGebra at different SAMR levels

Three students from the experimental group were interviewed about their experiences of learning geometric transformations with GeoGebra. The interview data were analyzed thematically, with particular attention to students' perceptions of the learning experience and their engagement as GeoGebra use progressed through the substitution, augmentation, modification, and redefinition levels of the SAMR model. The analysis identified several interrelated aspects of students' experiences, including enhanced visualization and conceptual understanding, exploration and active participation, motivation, collaboration, and the progressive transformation of learning activities across the SAMR levels.

Students' perceptions of their learning experiences varied according to the level at which GeoGebra was integrated into instruction. At the substitution level, students generally perceived GeoGebra as a digital alternative to the conventional tools they normally used in mathematics lessons. The software changed the medium through which geometric constructions were produced, but it did not substantially alter the nature of the learning task. S1 described this experience by stating, "*At first, it was like drawing with a computer, just like in our notebooks.*" This response indicates that the student initially viewed GeoGebra primarily as a replacement for pen-and-paper work rather than as a fundamentally different learning environment.

Although the use of a digital tool introduced a technological element into the lesson, students' accounts suggest that the learning experience at the substitution level remained relatively familiar. They continued to perform recognizable geometric tasks, with the main difference being that these tasks were completed digitally. Thus, students' initial perceptions reflected continuity with traditional instruction rather than substantial pedagogical change.

At the augmentation level, however, students began to recognize additional functional benefits of GeoGebra. In particular, its dynamic features allowed them to manipulate points and geometric shapes and immediately observe the effects of these changes. S2 explained, "*When I moved those points around and saw shapes change, I really got what we were learning.*" This response suggests that the interactive nature of GeoGebra contributed to a clearer and more concrete understanding of geometric transformations.

The ability to observe transformations dynamically appears to have changed students' experience from simply reproducing geometric constructions to actively observing relationships between mathematical actions and their visual consequences. Immediate visual feedback enabled students to see how changes in the position or properties of an object affected its transformation. Therefore, at the augmentation level, GeoGebra was perceived not merely as a digital replacement for traditional tools but as a resource that enhanced the existing learning task and made abstract geometric relationships more accessible.

Visualization emerged as an important aspect of students' positive perceptions of GeoGebra-supported learning. Geometric transformations can require learners to mentally represent changes in the position, orientation, or size of objects. GeoGebra enabled these changes to be displayed dynamically, allowing students to observe transformations rather than relying exclusively on static diagrams.

The interview responses suggest that this dynamic visualization helped students establish clearer connections between mathematical procedures and their outcomes. Instead of considering a transformation only as a sequence of rules, students could manipulate an object and observe how those rules affected its position or form. S2's description of moving points and watching shapes change illustrates how interaction with visual representations supported the student's understanding of the mathematical concepts being studied.

This perceived benefit became more evident as GeoGebra use moved beyond substitution. At the lower level, technology mainly changed the tool used to complete a familiar task. At the higher levels, visualization became increasingly connected with experimentation, exploration, and the construction of mathematical meaning. Students were therefore not simply viewing prepared representations; they were interacting with them and observing the consequences of their own actions.

A further theme emerging from the interviews was the role of GeoGebra in encouraging exploration and active participation. This was particularly evident at the modification level, where technology enabled substantial changes to the structure of the learning activities. Students reported that they were able to create and investigate their own dynamic problems rather than only completing tasks predetermined by the teacher or textbook.

S3 explained, *"We created our own dynamic problems. It felt like we were discovering things, not just learning from a book."* This statement reflects an important change in the student's perceived role in the learning process. Rather than functioning primarily as a recipient of mathematical information, the student described participating in the discovery of mathematical relationships.

The opportunity to create problems and manipulate geometric objects encouraged students to experiment with different possibilities and observe the resulting outcomes. Their engagement therefore involved more than completing assigned procedures. They could make changes, examine patterns, test possibilities, and respond to the visual results produced by the software. Such activities appear to have encouraged a more exploratory approach to geometric transformations.

The students' accounts also suggest that GeoGebra supported greater learner autonomy at this level. While teacher guidance remained important, students had increased control over how they explored the mathematical content. The learning process consequently became less dependent on reproducing teacher demonstrations and more focused on students' own interaction with geometric representations.

Students described the most substantial changes in their learning experiences at the redefinition level. At this stage, GeoGebra was used to support activities that students perceived as extending beyond those normally undertaken through conventional classroom resources. In particular, students referred to experimenting with three-dimensional transformations and dynamic simulations.

S2 described this experience enthusiastically: *"We went beyond the usual stuff. Making those 3D shapes move felt like magic. It was our own world of geometry."* The expression "beyond the usual stuff" is particularly indicative of the student's perception that the nature of the learning activity had changed. Rather than simply performing familiar tasks more efficiently, the student experienced forms of mathematical exploration that differed from routine classroom practices.

At the redefinition level, therefore, technology appeared to expand the range of learning experiences available to students. Dynamic simulations and manipulation of complex representations created opportunities to investigate geometric ideas in ways that students perceived as novel and engaging. This represents a progression from the substitution level, where technology mainly replaced conventional tools, toward a learning environment in which technology supported qualitatively different forms of interaction with mathematical content.

The students' responses indicate that this progression also influenced their engagement. More complex and exploratory activities appeared to generate curiosity and enthusiasm, encouraging students to investigate what could be achieved through the software. The redefinition level was consequently characterized not only by technological complexity but also by a stronger sense of discovery and student involvement.

Motivation was another recurring theme in students' descriptions of learning with GeoGebra. Students reported that the visual and interactive characteristics of the software encouraged them to continue exploring geometric problems. This motivational dimension appeared especially evident when students were able to manipulate objects, test possibilities, and immediately observe the consequences of their actions.

S3 stated, *"GeoGebra makes me want to see what happens next. It's like a challenge to see if I can make things fit perfectly."* This response illustrates how interaction with the software stimulated

curiosity and encouraged continued participation. The statement suggests that engagement was partly driven by the opportunity to experiment and receive immediate visual feedback.

Students' motivation was therefore associated not simply with the novelty of using technology but with the opportunities for active interaction that GeoGebra provided. As the tasks became more exploratory at the modification and redefinition levels, students were increasingly able to make decisions, investigate possible outcomes, and observe the results of their actions. Their engagement consequently became connected with inquiry and problem solving.

The interview responses also indicate a relationship between perceived challenge and engagement. Rather than describing the tasks solely in terms of difficulty, students appeared to perceive the interactive challenges as something that encouraged further exploration. This suggests that appropriately designed GeoGebra activities may help sustain students' attention by combining mathematical problem solving with immediate visual responses.

Students also identified collaboration as an important aspect of their engagement with GeoGebra. The software provided opportunities for learners to work together on dynamic representations, discuss the changes they observed, and share possible approaches to geometric problems. These collaborative activities contributed to students' perceptions of the lessons as more participatory and enjoyable.

S1 commented, "We could all work on the same thing together, like a team." It suggests that the learning experience was perceived as socially interactive rather than exclusively individual. Students were able to participate in shared exploration, compare observations, and contribute ideas while working with dynamic geometric representations. In this sense, engagement involved not only interaction between the learner and the software but also interaction among learners.

Collaborative engagement also appears to have complemented the exploratory nature of the higher SAMR levels. When students were given opportunities to construct problems, manipulate objects, or investigate simulations, working with peers allowed them to discuss alternative approaches and jointly interpret what they observed. GeoGebra therefore functioned as a shared environment around which mathematical interaction could occur.

Considering the interview findings across the four SAMR levels reveals a progressive transformation in how students perceived their learning experience. At substitution, students primarily recognized a change in the instructional medium: digital drawing replaced conventional drawing, while the fundamental task remained familiar. Their experience was therefore characterized mainly by technological replacement.

At augmentation, students began to identify functional improvements in the learning process. Dynamic manipulation and immediate visual feedback enhanced existing activities and helped make geometric transformations more understandable. Engagement increased because students could interact directly with mathematical representations rather than merely observe static examples.

Considering modification, the role of the learner changed more substantially. Students were able to create dynamic problems, investigate relationships, and participate actively in discovering mathematical patterns. The learning experience became increasingly exploratory and learner-centered, with students exercising greater autonomy over their interaction with geometric concepts.

Finally, at redefinition, students described experiences involving dynamic simulations and complex representations that they perceived as extending beyond conventional classroom activities. These experiences were associated with enthusiasm, experimentation, and a strong sense of discovery. The higher SAMR levels therefore appeared to provide greater opportunities for active and transformative engagement than the lower levels.

The progression across the SAMR framework was thus reflected not only in the technological characteristics of the activities but also in students' perceptions of their own participation. As GeoGebra integration moved from substitution toward redefinition, students described a corresponding movement from completing familiar tasks digitally toward exploring, creating, collaborating, and experimenting with mathematical ideas.

The interviewed students generally perceived learning geometric transformations with GeoGebra positively, but their perceptions of the learning experience and engagement varied according to the level of integration represented by the SAMR model. At the lower levels,

GeoGebra primarily replaced or enhanced familiar classroom practices, whereas at the higher levels it supported increasingly exploratory, collaborative, and student-centered activities.

The findings therefore suggest that students did not perceive the educational value of GeoGebra as uniform across all levels of technology integration. Its perceived contribution increased when its dynamic and interactive capabilities were used to change the nature of the learning activity rather than simply replace conventional instructional tools. In particular, the modification and redefinition levels provided opportunities for students to become more active participants in the learning process by exploring mathematical relationships, creating problems, collaborating with peers, and engaging with dynamic representations.

5. Discussion

The investigation into the impact of GeoGebra integration on students' geometric transformation learning journey yielded insightful results. Specifically, the analysis focused on students' pre-test and post-test performance in both the Control and Experimental groups. The absence of a significant difference in pre-test scores between the control and experimental groups is consistent with the observations made by Jackson (2017) on technology integration. It was noted that initial performance similarities among different instructional groups contribute to the robustness of subsequent intervention comparisons. Our study's results further validate the importance of establishing a balanced baseline.

The calculated t-value of 0.285 with a corresponding p-value of 0.82 in the independent samples t-test on pre-test scores reaffirm the notion that, at the onset, the two groups displayed comparable levels of proficiency. This concurs with the findings of similar investigations. For example, Hegedus et al. (2016) observed no significant disparity in pre-test scores before technology intervention. Turning our attention to post-test results, Grandgenett (2008) found that technology integration can lead to enhanced academic outcomes, aligning with our observation of significantly higher post-test scores in the Experimental group.

The enhancement of learning experiences due to GeoGebra integration, as indicated in students' responses, is in consonance with the findings of (Sakina & Zineb, 2013; Munyaruhengeri et al., 2025). They identified that interactive technology tools like GeoGebra promote active engagement and offer novel ways to explore mathematical concepts, corroborating our study's emphasis on enhanced engagement and active participation.

Furthermore, our study echoes the sentiments of Jude et al. (2014) as well as Zamri and Mohamad (2025), who identified that technology integration, particularly at the re-definition level, empowers students to delve into complex tasks. The excitement voiced by students about 3D transformations and simulations at higher SAMR levels resonates with Adesina & Sosanwo (2025) whose findings on students' heightened enthusiasm for technology-driven challenges.

The findings suggest that the effectiveness of GeoGebra extends beyond improving examination performance. Its value lies in creating an interactive learning environment that promotes conceptual understanding, visualization, inquiry, collaboration, and sustained learner motivation. Within the Ghanaian mathematics classroom context, where students often experience difficulties in understanding abstract geometric concepts through traditional teaching methods, GeoGebra offers a practical instructional approach that can enhance both the quality of classroom instruction and students' achievement in geometry. These findings therefore provide empirical support for integrating GeoGebra into mathematics instruction and underscore the need for teacher professional development and institutional investment in technology-supported mathematics education.

The findings of this study present important implications for mathematics education, instructional practices, curriculum development, and educational policy. First, the significant improvement in the achievement of students exposed to GeoGebra instruction suggests that integrating dynamic mathematics software into classroom teaching can substantially enhance students' understanding of geometric transformations. This indicates that technology supported instruction can serve as an effective alternative to conventional teaching approaches, particularly in abstract mathematical topics where students often experience learning difficulties (Yildirim, 2025; Kadluba et al., 2025).

Second, the study highlights the importance of learner-centered pedagogical approaches in mathematics instruction. GeoGebra integration encouraged active participation,

exploration, and discovery learning, allowing students to manipulate geometric objects and observe transformations dynamically. This implies that teachers should adopt instructional strategies that actively involve students in the learning process rather than relying solely on traditional lecture-based methods (Dzaiy & Abdullah, 2024).

Third, the visual and interactive features of GeoGebra contribute significantly to students' conceptual understanding and spatial reasoning abilities. The software enables learners to visualize abstract mathematical concepts in concrete and meaningful ways, thereby improving comprehension and retention (Lubis et al., 2025). Mathematics educators can therefore use GeoGebra to simplify difficult concepts and support deeper mathematical thinking.

Additionally, the findings demonstrated that students became more motivated and engaged when GeoGebra was integrated into instruction. Increased motivation and positive attitudes toward mathematics are critical factors in improving students' academic performance and reducing mathematics anxiety (Lotey et al., 2025; Mensah et al., 2026). This suggests that technology integration can make mathematics learning more enjoyable, stimulating, and relevant to students' experiences.

The study also revealed that GeoGebra promotes collaborative learning through shared exploration and interactive activities. Students reported that working together with peers enhanced their learning experiences and encouraged teamwork and communication. This has implications for classroom organization, as teachers can design collaborative tasks and group-based activities that foster peer interaction and cooperative problem-solving (Gurmu, 2024; Ndagijimana et al., 2024).

Furthermore, the study emphasizes the importance of teacher competence in technology integration. Effective implementation of GeoGebra requires teachers to possess both technological and pedagogical knowledge. Consequently, teacher education institutions and educational authorities should organize continuous professional development programs and workshops to equip teachers with the skills needed to integrate ICT tools effectively into mathematics instruction (Assadi & Cretu, 2023; Benning et al., 2023). Finally, the study contributes to the development of 21st-century learning competencies such as critical thinking, creativity, digital literacy, communication, and problem-solving skills. By engaging students in interactive and technology-based learning environments, GeoGebra integration prepares learners to function effectively in an increasingly digital and knowledge-driven society.

5. Conclusions

This study examined the impact of GeoGebra integration on students' learning of geometric transformations and explored students' perceptions of their learning experiences within the framework of the SAMR model. The findings provide compelling evidence that integrating GeoGebra into geometry instruction significantly enhances students' academic achievement and enriches their overall learning experiences. While the pre-test results indicated no statistically significant difference between the Control and Experimental groups, confirming that both groups had comparable levels of prior knowledge before the intervention, the post-test results revealed a significant improvement in the achievement of students who learned geometric transformations using GeoGebra. This demonstrates that the observed gains in performance can be attributed to the instructional intervention rather than differences in students' initial mathematical ability.

The study further established that GeoGebra creates a more interactive, engaging, and learner-centered classroom environment. Students reported positive learning experiences characterized by increased motivation, active participation, improved visualization of geometric concepts, and greater opportunities for exploration and collaboration. As the integration of GeoGebra progressed across the SAMR model from substitution to re-definition, students experienced increasingly meaningful and authentic learning activities that promoted conceptual understanding rather than procedural memorization. These findings suggest that GeoGebra not only improves students' academic performance but also enhances higher-order thinking skills, problem-solving abilities, and confidence in learning geometry.

The study contributes to the growing body of evidence supporting the educational value of dynamic mathematics software in mathematics instruction. It demonstrates that when GeoGebra is purposefully integrated into classroom teaching, it can transform the learning of abstract concepts such as geometric transformations into meaningful visual and inter-active

experiences. The findings therefore underscore the importance of equipping mathematics teachers with the pedagogical and technological competencies required to integrate GeoGebra effectively into their instructional practices.

Overall, this study concludes that GeoGebra is an effective instructional tool for teaching geometric transformations. Its integration enhances students' achievement, engagement, conceptual understanding, and motivation, making it a valuable resource for contemporary mathematics education. Consequently, schools, teacher education institutions, and educational policymakers should promote the effective adoption of GeoGebra through adequate technological infrastructure, curriculum support, and continuous professional development for mathematics teachers.

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