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Enhancing Student Achievement in Circle Theorems: Integrating Computer Animation with the Jigsaw Cooperative Learning Model

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ABSTRACT

Purpose – Geometry plays a crucial role in developing cognitive skills such as spatial reasoning, visualization, and problem-solving. However, many students in Ghanaian senior high schools face difficulties with abstract topics like circle theorems. This study examines the effectiveness of combining jigsaw cooperative learning with computer animation to improve students' conceptual understanding of geometric concepts compared to traditional teaching methods.

Methodology – A quasi-experimental design was adopted involving senior high school students assigned to control and experimental groups. The control group received conventional instruction, while the experimental group was taught using jigsaw cooperative learning supported by computer animations. Pre-test and post-test data were collected and analyzed using the Mann-Whitney U test due to non-normal data distribution.

Findings– Students in the experimental group significantly outperformed those in the control group, demonstrating higher post-test scores. The integration of cooperative learning and visual animation enhanced conceptual understanding, reduced cognitive load, and improved knowledge retention.

Novelty – This study offers a unique contribution by integrating jigsaw learning with computer animation—a combination rarely explored in teaching abstract geometry. Conducted in a sub-Saharan African context, it extends limited research on multimedia-supported instruction by focusing not only on academic performance but also on deeper cognitive outcomes.

Significance – The findings underscore the potential of technology-enhanced collaborative strategies in improving learning in abstract mathematical domains. The study provides evidence-based recommendations for adopting innovative pedagogies in low-resource educational settings, with implications for curriculum development and teacher training.

Keywords: Circle theorem; Computer animation; Geometry; Jigsaw; Traditional method.

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1. Introduction

Geometry is a fundamental branch of mathematics that plays a vital role in developing logical reasoning, spatial awareness, and problem-solving skills (Hershkowitz, 2020). Its applications range from simple tasks such as navigating spaces to more complex fields including engineering and architecture (Fabiyi, 2017). Despite its significance, geometry remains one of the most challenging subjects for students worldwide, including those in Ghanaian senior high schools. Among various topics in geometry, circle theorems are particularly difficult due to their abstract nature and the necessity for strong visual-spatial reasoning (Asemani, Asiedu-Addo, & Oppong, 2017; Hissan & Ntow, 2021). As a result, poor student performance in this area continues to be a pressing issue. The struggle with geometry is part of a broader issue in mathematics education in Ghana. Reports from international assessments, such as the Trends in International Mathematics and Science Study (TIMSS), indicate that Ghanaian students consistently score below international benchmarks in mathematics (Davis, Carr, & Ampadu, 2019). Geometry has been highlighted as one of the weakest areas for students, raising concerns about current teaching methods (Enu, Danso, & Awortwe, 2015).

One of the main contributors to this underperformance is the widespread use of teacher-centered instructional methods in Ghanaian classrooms (Ashiboe-Mensah, 2021). In this model, teachers serve as the primary source of knowledge, while students assume passive roles as receivers of information. Lessons typically consist of lectures, procedural demonstrations, and pre-determined solutions, with students expected to memorize facts and reproduce them in exams. This method often leads to surface-level learning, where students memorize concepts without a true understanding of their underlying principles (Mwangi, Changeiywo, & Nyingi, 2018). Furthermore, traditional teacher-centered instruction does not accommodate the diverse learning styles of students, which is particularly detrimental in geometry, a subject that heavily relies on visualization and interaction (Hershkowitz, 2020). Traditional teaching methods often rely on teacher-centered instruction, which limits student engagement and fails to accommodate diverse learning styles. The Jigsaw model addresses these limitations by fostering collaborative learning and allowing students to construct their understanding through peer interaction.

Traditional teaching methods are predominantly teacher-centered, emphasizing direct instruction, where educators deliver knowledge to students through structured lectures, presentations, and predetermined curricula (Jin & Peng, 2022). This instructional model is characterized by face-to-face engagement, with teachers guiding the learning process while students assume largely passive roles as recipients of information. Typically, traditional methods prioritize rote memorization, factual recall, and adherence to rigid lesson plans, which results in minimal student interaction and limited active participation (Hu, 2024). Jin et al. (2021) investigated the transition from traditional to e-learning during the COVID-19 pandemic and noted that traditional methods faced significant challenges when face-to-face instruction was disrupted. Their research highlights that, while these methods provide a structured and controlled learning environment, they often struggle to adapt to digital platforms and fail to engage students dynamically. The heavy reliance on in-person instruction and direct teacher-student interaction hindered the effective transition of traditional teaching methods into online learning formats. Hafeez (2021) critiques traditional teaching models for their one-way communication approach, in which teachers deliver content without fostering active student engagement. This method frequently results in passive learning environments, limiting students' opportunities to ask questions, interact with concepts, or participate in discussions. Although traditional methods allow for efficient transmission of large amounts of information, they do not effectively cultivate critical thinking, creativity, or problem-solving skills. Additionally, the lack of immediate feedback mechanisms prevents students from reflecting on their learning and improving their understanding before assessments.

Hu (2024) examines traditional teaching in secondary education and asserts that, while these methods are effective for foundational learning, they fail to address the diverse cognitive needs of students. The rigid and authoritative structure of traditional classrooms suppresses individuality and limits opportunities for exploration and creative thinking. Hu further highlights psychological concerns, including increased anxiety and disengagement, which arise from a strict, teacher-dominated classroom environment. This rigid instructional approach often renders learning less meaningful, as students struggle to connect theoretical knowledge with real-world applications.

Wang et al. (2022) acknowledge the historical preference for traditional teaching methods, citing their effectiveness in conveying core knowledge and preparing students for standardized assessments. However, Wang also critiques this approach for fostering a passive learning environment, where students become overly dependent on teachers for knowledge acquisition, thereby hindering self-directed learning and initiative. The heavy emphasis on memorization and examination performance often leads to superficial understanding, leaving students ill-equipped to apply knowledge in practical contexts.

While traditional teaching methods offer structure and efficiency, they often restrict student engagement, creativity, and the development of critical thinking skills. The challenges posed by the COVID-19 pandemic, combined with evolving student needs, underscore the necessity for more innovative and student-centered teaching approaches. Instructional strategies that incorporate cooperative learning, multimedia tools, and interactive methodologies have the potential to enhance student engagement, promote deeper learning, and better equip learners with essential 21st-century skills. Therefore, it is imperative to explore and implement alternative pedagogical approaches that cater to diverse learning styles, while simultaneously fostering active participation, creativity, and real-world application of knowledge.

One of the primary factors contributing to underperformance in mathematics education is the continued reliance on teacher-centered instruction, particularly in Ghanaian classrooms (Ashiboe-Mensah, 2021). In this model, the teacher assumes the role of the primary source of knowledge, while students remain passive recipients, focusing primarily on memorization and reproduction of facts. The traditional classroom dynamic is often structured around teacher-led lectures, procedural demonstrations, and pre-determined solutions, with students expected to absorb and replicate information without active engagement. Such an instructional approach frequently results in surface-level learning, where students memorize concepts without fully internalizing or understanding their applications (Mwangi, Changeiywo, & Nyingi, 2018).

Conventional teaching methods fail to accommodate the diverse cognitive and learning styles of students, which contributes to the persistent difficulties many learners face in understanding mathematical concepts. Geometry, particularly topics such as circle theorems, requires students to visualize, manipulate, and explore geometric relationships to grasp their underlying properties. However, traditional teacher-centered instruction does not sufficiently foster the critical thinking, active engagement, or exploratory learning necessary for students to master these abstract concepts (Hershkowitz, 2020). In such a learning environment, students are rarely provided opportunities to actively participate, collaborate, or engage in inquiry-based problem-solving activities that would enable them to construct their own understanding of the material. Boaler et al. (2022) emphasize that when students are not encouraged to engage deeply with mathematical concepts, they struggle to apply them in real-world problem-solving situations. This lack of engagement leads to a decline in student confidence and lower academic achievement in mathematics. Without interactive learning experiences that facilitate exploration and conceptual discovery, students tend to perceive mathematics as a rigid and abstract discipline, further exacerbating their struggles with the subject.

In contrast, student-centered approaches are designed to actively engage learners in the learning process by emphasizing inquiry, collaboration, and the application of knowledge in meaningful contexts (Tay & Wonkyi, 2018). Rather than passively receiving information, students in student-centered classrooms are encouraged to ask questions, explore mathematical ideas, engage in peer discussions, and construct their own understanding through active participation. This pedagogical shift from teacher-centered to student-centered instruction is particularly critical in the teaching of geometry, where conceptual understanding and spatial reasoning play an essential role in student success.

Empirical studies provide strong support for the effectiveness of student-centered instructional strategies in improving mathematics achievement. Research findings indicate that students who learn through collaborative, inquiry-based, and hands-on approaches develop a deeper and more meaningful engagement with mathematical concepts (Hawkins, 2024). Furthermore, such approaches encourage problem-solving, logical reasoning, and critical thinking skills, which are essential for success in both mathematics education and STEM-related disciplines. Beyond short-term academic improvements, the Jigsaw method with animation fosters deeper conceptual understanding, which enhances long-term retention and problem-solving skills in geometry.

A student-centered approach has been widely recognized as a more effective alternative to conventional, teacher-centered instruction in mathematics education. Unlike traditional methods, which emphasize rote memorization and passive reception of knowledge, student-centered approaches encourage active engagement, inquiry-based exploration, and peer collaboration, fostering a deeper and more meaningful understanding of mathematical concepts (Tay & Wonkyi, 2018, Earnest et al, 2024). This instructional model shifts the focus from teacher-led lectures to learner-driven activities, where students play an active role in constructing their own knowledge through discussions, problem-solving, and interactive learning experiences. By engaging with mathematical concepts in a dynamic and participatory manner, students develop higher-order thinking skills, critical reasoning, and a stronger ability to apply mathematical principles in real-world contexts.

Among the most effective student-centered instructional strategies is the Jigsaw Cooperative Learning Model, which promotes collaborative learning by dividing complex topics into smaller, manageable segments that student's research, master, and then teach to their peers. This approach fosters a sense of responsibility, peer-to-peer learning, and active engagement, making it particularly effective in improving students' comprehension and retention of mathematical concepts. Research indicates that cooperative learning strategies such as Jigsaw improve student motivation, problem-solving skills, and academic achievement by encouraging meaningful discussions and critical analysis of subject matter (Johnson, Johnson, & Smith, 2024).

In addition to cooperative learning, computer animation serves as a powerful visualization tool that enhances students' understanding of abstract mathematical concepts, particularly in geometry. Since geometry heavily relies on spatial reasoning and visual interpretation, the use of dynamic, interactive animations allows students to observe geometric transformations in real time, making it easier to grasp the relationships between angles, shapes, and theorems (Gambari, Falode, & Adegbenro, 2014). By integrating multimedia elements, computer animation not only makes learning more engaging and interactive but also bridges the gap between theoretical knowledge and practical application, helping students develop a stronger conceptual foundation in mathematics.

When Jigsaw cooperative learning is combined with computer animation, it creates a powerful blended instructional model that maximizes student engagement, enhances conceptual understanding, and improves knowledge retention. The collaborative nature of the Jigsaw method, combined with the visual reinforcement provided by animation, ensures that students not only learn mathematical concepts deeply but also develop critical thinking, teamwork, and digital literacy skills, all of which are essential for success in STEM education and beyond. Developed by Aronson (1978), the Jigsaw method is a group-based collaborative learning strategy in which each student is responsible for mastering a specific portion of the material and then teaching it to their peers. This interactive approach transforms students from passive recipients of knowledge into active participants, fostering engagement, motivation, and self-efficacy (Johnson, Johnson, & Smith, 2024).

In the context of geometry education, Jigsaw learning enables students to collaboratively explore geometric properties and theorems, leading to a deeper conceptual understanding. Peer discussions facilitate knowledge sharing, clarification of misconceptions, and exposure to multiple perspectives, all of which are critical for mastering abstract concepts such as circle theorems. Research has consistently shown that cooperative learning techniques outperform competitive or individual learning methods in developing higher-order thinking skills and achieving better learning outcomes (Enu et al., 2015; Geletu, 2022; Takko et al., 2020). Beyond academic achievement, it enhances social skills, collaborative abilities, and overall engagement in learning (Akkus & Doymus, 2022; Kenedi, Eliyasni, & Fransyaigu, 2019; Rahmawati, Poba, Magfirah, & Burase, 2022).

The Jigsaw method is a structured form of cooperative learning in which each member of a group is assigned a specific role and set of tasks (Karacop, 2017; Kenedi et al., 2019). Students begin by working in expert groups, where those assigned the same learning task come together to research, discuss, and develop expertise in their designated topics. After acquiring knowledge, students return to their original Jigsaw groups to teach their peers, ensuring that every member gains a comprehensive understanding of the subject matter.

1. Individual accountability – Each student becomes an expert in one aspect of the material (E. Aronson, 1978; Saputra, Joyoatmojo, Wardani, & Sangka, 2019).
2. Positive interdependence – Students rely on one another to share and integrate their knowledge, reinforcing collaborative learning (D. W. Johnson & Johnson, 1992).

The Jigsaw approach provides an effective collaborative learning environment that promotes active student engagement, mutual knowledge acquisition, and peer explanations (Karacop, 2017). Empirical research indicates that students taught using the Jigsaw method develop a deeper understanding of subject matter compared to those taught using conventional, teacher-centered methods (Gambari et al., 2014; Kenedi et al., 2019; Olamigoke, 2021). Similarly, Namaziandost, Homayouni, and Rahmani (2020) found that students enjoyed using the Jigsaw cooperative learning approach and experienced significant improvements in their academic performance.

Another innovative pedagogical advancement that has shown great promise in improving student outcomes in mathematics is the use of computer animation. Geometry heavily relies on visual representation, making computer animation a valuable tool for enhancing students' understanding of abstract concepts (Gambari, Falode, & Adegbenro, 2014). Computer animations provide dynamic visualizations, enabling students to observe how geometric theorems and properties function in real-time. For example, animations can illustrate how angles and segments transform as a circle rotates, making abstract relationships more tangible and comprehensible. According to Mwangi et al. (2018), integrating multimedia into geometry instruction helps bridge the gap between theoretical mathematical concepts and practical applications, resulting in improved student comprehension and knowledge retention. Dwyer and Dwyer (2003) describe computer animation as moving visuals that enhance learning engagement. Their study highlights that computer animation promotes flexibility in learning, provides a wider variety of stimuli, and increases student engagement. Similarly, Asiedu (2022) affirms that computer animation enhances motivation, simplifies complex systems, and significantly improves academic achievement. Given the abstract nature of geometry concepts, which are often difficult to understand through text-based explanations alone, visualization techniques such as animations provide accurate and rich depictions of these concepts (Akay et al., 2022; Bremer et al., 2022).

The Dual-Coding Theory proposed by Paivio (2014) explains the effectiveness of computer animations as educational tools. The theory suggests that students retain information in their working memory through two primary cognitive channels: verbal (linguistic) and visual (pictorial) mental representations. Visualization is particularly essential in teaching circle theorems, as it allows students to develop mental images that enhance problem-solving and conceptual understanding. According to the Senior High School (SHS) Teaching Syllabus for Core Mathematics in Ghana (MOE, 2010), the general objectives of learning geometry depend on a student's ability to analyze a problem, select an appropriate strategy, and apply that strategy to find a solution. However, research suggests that computer animations alone may not be sufficient to enhance students' knowledge and understanding (Aysolmaz & Reijers, 2021; Puspaningtyas & Ulfa, 2020). Therefore, combining diverse instructional strategies with animations is necessary to maximize student comprehension of mathematical concepts. This study aims to examine the effectiveness of integrating computer animation with the Jigsaw cooperative learning model in improving students' achievement in circle theorems in the Kwabre East Municipality in the Ashanti Region of Ghana.

Comparison of Teaching Methods: Control vs. Proposed ApproachTo evaluate the effectiveness of the proposed Jigsaw cooperative learning strategy integrated with computer animation, this study compared it with the conventional teacher-centered approach. In the control class, instruction adhered to the traditional model, where the teacher delivered direct instruction, demonstrated proofs, and provided solutions, while students took notes and memorized theorems. Assessments focused primarily on recall-based testing, with limited emphasis on conceptual understanding. Student engagement in this environment was minimal, with few opportunities for peer discussions or collaborative problem-solving.

Conversely, the experimental class employed the Jigsaw cooperative learning model integrated with computer animation. Each student was responsible for learning a specific component of the circle theorems and teaching it to their peers, fostering active engagement and deeper comprehension. Animated representations of geometric concepts provided an interactive and dynamic visualization, reinforcing spatial reasoning. This blended instructional approach facilitated collaborative learning and cognitive engagement, addressing the shortcomings of the conventional method.

To assess the effectiveness of the proposed Jigsaw cooperative learning strategy integrated with computer animation, this study compared it with the conventional teacher-centered approach used in the control class. The objective of this comparison was to evaluate the extent to which the student-centered approach enhances conceptual understanding, problem-solving skills, and student engagement in learning circle theorems (Karacop, 2017; Kenedi et al., 2019).

In the control class, instruction followed a traditional model, where the teacher played a central role in delivering direct instruction, demonstrating proofs, and providing solutions. Students were expected to take notes, memorize theorems, and replicate procedural techniques in examinations. The learning process was predominantly passive, as students primarily absorbed information without actively engaging with the material (Hu, 2024). Assessments in this setting were recall-based, focusing on the reproduction of facts and formulas rather than testing deep conceptual understanding or problem-solving abilities (Mwangi, Changeiywo, & Nyingi, 2018). Consequently, student engagement remained low, with limited opportunities for peer discussions, interactive learning, or collaborative problem-solving activities. The absence of interactive elements restricted students' ability to visualize geometric concepts effectively, making it more difficult for them to grasp the abstract relationships within circle theorems (Hissan & Ntow, 2021).

Conversely, the experimental class adopted an active learning approach by implementing the Jigsaw cooperative learning model integrated with computer animation. In this setting, each student was assigned a specific component of the circle theorems, which they were required to study in depth and then teach to their peers. This peer-teaching structure not only fostered active participation but also encouraged students to take responsibility for their own learning, leading to greater motivation and engagement (Johnson, Johnson, & Smith, 2024). The collaborative nature of the Jigsaw model provided students with opportunities to discuss concepts, clarify misconceptions, and build a deeper understanding through interaction with their peers (Namaziandost, Homayouni, & Rahmani, 2020).

The integration of computer animation further enhanced the learning experience by providing dynamic visualizations of geometric properties, allowing students to observe and manipulate transformations in real time (Gambari, Falode, & Adegbenro, 2014). Unlike the static representations in traditional textbooks, animated models enabled students to visualize the relationships between angles, chords, and tangents as a circle rotated, thereby reinforcing spatial reasoning skills (Akay et al., 2022; Bremer et al., 2022). This interactive approach bridged the gap between abstract mathematical theory and practical application, making the learning process more engaging and meaningful (Dwyer & Dwyer, 2003; Asiedu, 2022). By shifting from a passive learning environment to an interactive and student-centered model, the Jigsaw cooperative learning approach with computer animation encouraged students to actively engage, collaborate, and develop a more profound conceptual understanding of circle theorems (Enu et al., 2015; Geletu, 2022; Takko et al., 2020).

The integration of Jigsaw cooperative learning and computer animation in geometry instruction has the potential to yield long-term benefits that extend beyond immediate academic performance. This approach promotes deeper conceptual understanding by encouraging students to actively engage with geometric principles rather than passively memorizing formulas and theorems. Through collaborative discussions and peer teaching, students develop a more profound comprehension of geometric relationships, making it easier for them to apply these concepts in various mathematical and real-world contexts (Karacop, 2017; Kenedi et al., 2019). Research has shown that cooperative learning strategies like Jigsaw improve students' ability to analyze and integrate information, leading to a stronger conceptual grasp of mathematical principles (Boaler et al., 2022).

Furthermore, the proposed method enhances problem-solving skills by fostering an interactive learning environment where students are encouraged to explore different problem-solving techniques. The Jigsaw method requires students to analyze information critically, explain their understanding to peers, and integrate different perspectives, all of which strengthen their ability to think analytically and approach mathematical challenges with confidence (Gambari et al., 2014). Studies indicate that students who engage in cooperative learning environments demonstrate improved problem-solving abilities due to the necessity of explaining concepts to their peers and integrating multiple viewpoints (Namaziandost, Homayouni, & Rahmani, 2020).

In addition to improving individual cognitive skills, this approach reinforces collaboration and self-directed learning. By working in groups, students develop essential teamwork and communication skills that are crucial for both academic success and future professional environments (Kenedi, Eliyasni, & Fransyaigu, 2019; Rahmawati, Poba, Magfirah, & Burase, 2022). The collaborative nature of Jigsaw learning instills a sense of responsibility, as each student is accountable for mastering a specific concept and ensuring that their peers understand it as well (D. W. Johnson & Johnson, 1992). At the same time, the incorporation of computer animation fosters independent exploration, allowing students to visualize and interact with complex geometric transformations, thereby strengthening their ability to learn autonomously (Gambari, Falode, & Adegbenro, 2014).

Moreover, this blended instructional model contributes to improved performance in STEM-related subjects. Since STEM disciplines rely heavily on spatial reasoning, logical thinking, and problem-solving, the ability to conceptualize and manipulate geometric structures dynamically gives students a strong foundation for success in fields such as engineering, physics, and computer science (Akay et al., 2022; Bremer et al., 2022). By bridging the gap between theoretical knowledge and practical application, this approach better prepares students for advanced studies and careers in STEM fields (Mwangi et al., 2018). Research supports the notion that multimedia-enhanced instruction, particularly through the use of animations, improves students' engagement and comprehension in STEM subjects (Dwyer & Dwyer, 2003; Asiedu, 2022).

Given the challenges associated with traditional, teacher-centered approaches in teaching geometry, this innovative blended instructional model represents a promising solution for improving students' achievement in circle theorems. The combination of cooperative learning and technology-enhanced visualization ensures that students not only understand geometric concepts more effectively but also retain and apply this knowledge in meaningful ways (Aysolmaz & Reijers, 2021; Puspaningtyas & Ulfa, 2020). By transforming the learning experience into an engaging, student-driven process, this approach has the potential to positively impact both academic success and lifelong learning skills. Beyond short-term academic improvements, the Jigsaw method with animation fosters deeper conceptual understanding, which enhances long-term retention and problem-solving skills in geometry.

2. Methods

2.1. Research Approach

This study adopted a quantitative research approach, which is grounded in a post-positivist philosophical framework that emphasizes objectivity, empirical evidence, and systematic data collection for statistical analysis (Maksimovic & Evtimov, 2023). Quantitative research provides a structured and replicable means of examining relationships between variables, measuring outcomes, and generalizing findings to a broader population. The rationale for selecting a quantitative approach in this study was to gather objective, measurable data that directly address the research questions regarding the effectiveness of an integrated Jigsaw cooperative learning and computer animation pedagogical strategy in enhancing students' understanding of circle theorems. This study utilized pre-tests and post-tests to assess student performance before and after the intervention, thereby providing empirical evidence of the instructional approach's impact. Statistical comparisons of student scores enabled a rigorous analysis of learning gains attributable to the innovative instructional strategy. The philosophical foundation for this research aligns with post-positivism, which advocates for the use of rigorous, systematic methods to test hypotheses and draw valid, generalizable conclusions (Maksimovic & Evtimov, 2023). By adopting a quantitative, quasi-experimental approach, this study aimed to contribute empirically grounded insights that can inform pedagogical practices and support evidence-based improvements in mathematics education.

2.2. Research Design

This study employed a quasi-experimental research design, which is commonly utilized when random assignment of participants is not feasible. A quasi-experimental approach enables the systematic examination of causal relationships by comparing outcomes between an experimental group and a control group (Maksimovic & Evtimov, 2023). In this study, the experimental group received instruction using a combination of Jigsaw cooperative learning and computer animation, while the control group was taught using traditional teaching methods.

The control group followed a teacher-centered, lecture-based instructional model, which is characterized by direct instruction, teacher-led demonstrations, and guided practice exercises. Lessons were primarily delivered in a structured format, where students were expected to listen, take notes, and complete textbook exercises individually, with minimal peer interaction. The teacher provided explicit explanations of circle theorems, followed by step-by-step demonstrations of proofs, ensuring that students followed a standardized sequence of instruction. After these demonstrations, students were assigned individual practice tasks under teacher supervision, reinforcing the rote memorization and procedural mastery that typify traditional mathematics instruction.

Unlike the experimental group, which incorporated collaborative problem-solving and interactive visualizations through animations, the control group relied exclusively on static representations of geometric concepts. Instruction was focused on procedural fluency rather than conceptual exploration, limiting opportunities for students to actively engage with the material beyond direct instruction. While this structured, lecture-based approach has been widely used in mathematics classrooms, it often emphasizes knowledge transmission over student interaction and discovery-based learning. By maintaining a clear distinction between instructional methods in the two groups, this study ensured a valid comparative analysis of the effectiveness of student-centered, technology-enhanced pedagogy against traditional instructional approaches.

2.3. Population of the Study Area

The Kwabre East Municipality serves as the geographical context for this study, which examines the impact of integrating jigsaw cooperative learning with computer animation on students' achievement and motivation in geometry, specifically in teaching circle theorems. The educational system in this municipality provides a rich setting for the research due to its extensive network of schools, spanning from preschools to a private university.

Covering 148 square kilometers, with the municipal capital of Mamponteng located 14.5 kilometers from Kumasi, the municipality consists of 43 communities, organized into 6 Zonal Councils and 31 Electoral Areas (Kwabre East Municipal-Mamponteng, 2023). This network includes 169 preschools, 170 primary schools, 136 Junior High Schools, 9 Senior High Schools, and a private university (Garden City University College in Kenyase), all serving the educational needs of the residents in Mamponteng and surrounding areas. Such a comprehensive educational infrastructure makes Kwabre East Municipality an ideal setting for evaluating the effects of innovative teaching methods on students' academic outcomes in mathematics.

By offering access to a diverse student population across multiple educational levels, particularly the 9 Senior High Schools, this area allows the study to assess how modern pedagogical techniques, like the integration of jigsaw cooperative learning and computer animation, can enhance learning in various academic environments. The municipality's strong commitment to developing quality education underscores the relevance of this research, which aims to contribute to ongoing efforts to improve students' academic achievement and motivation in schools across the area (Kwabre East Municipal – Mamponteng, 2023).

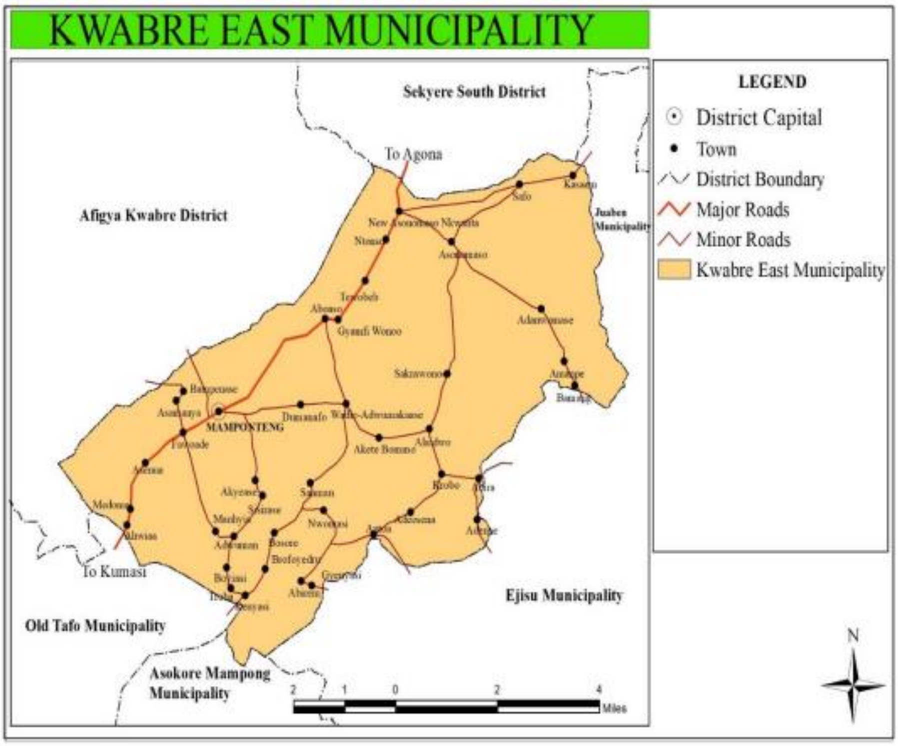

Figure 1. Map of the Kwabre East municipality

The participants for this study consisted of all second-year senior high school (SHS) elective mathematics students attending public schools within the Kwabre East Municipality that have functional computer laboratories. Eligibility for selection was limited to second-year students enrolled in elective mathematics courses at these public SHS institutions, provided the schools had access to operational computer labs. The rationale for selecting this specific student's pool is threefold:

a. *This study aimed to generalize its findings to senior high school (SHS) students within the Kwabre East Municipality who had access to technology, specifically functional computer labs. Consequently, the sample was drawn directly from this population to ensure relevance and applicability.*
b. *The decision to focus exclusively on public schools was made to better reflect the experiences of the majority of students in the municipality, as public schools typically*

account for a larger proportion of the student population compared to private institutions.

c. *Restricting the sample to second-year students was purposeful, as these students had greater exposure to their schools' computer lab resources compared to first-year students. Additionally, according to the Ghana Education Service syllabus for core mathematics, circle theorems are taught in the second year, making these students more familiar with the subject and better equipped to provide meaningful insights into the use of technology in their learning.*

d. *To ensure the alignment of the study with its objectives, schools included in the sample were verified to have practical access to functional computer labs. Excluding schools without operational computer labs avoided discrepancies in participants' technology experiences that might have undermined the study's research aims.*

e. *Administering assessment tools uniformly across the representative participant pool ensured the findings were both valid and generalizable to the broader population of second-year SHS students in the municipality with access to school computer technology.*

2.4. Sample Size and Sampling Technique

In this study, the sample was selected using purposive sampling. Two senior high schools, School A and School B, were chosen as the sites for the experimental group based on availability of adequate ICT facilities in the school. The study employed experienced professional mathematics teachers due to their expertise in the subject matter and their ability to effectively deliver the prescribed teaching methods. Purposive sampling was employed to select "information-rich" schools (Campbell et al., 2020). By using purposive sampling, a deliberate effort was made to select schools that met the specific criteria necessary for the study, such as having at least ten functional computers in the computer laboratories with a standby generator. This number was deemed adequate based on the group sizes and intervention design, where students worked in groups to ensure equal access. Additionally, the schools were located at a distance from each other to avoid undue interaction among participants from different schools (Campbell et al., 2020).

After selecting the schools, they were randomly assigned to one of the following groups: the jigsaw with computer animation instructional mode, or the traditional/conventional teaching methods. Random assignment helps to distribute potential confounding variables evenly across the groups, making the groups more comparable and reducing the likelihood of systematic differences between them (Deaton & Cartwright, 2018). Also, by randomly assigning schools to each group, the researcher aimed to create two groups that were similar in all aspects except for the type of instructional mode used. This allowed for a more accurate assessment of the effectiveness of each instructional mode, as any differences in outcomes between the groups could be attributed to the different teaching methods rather than other factors.

Within each selected school, purposive sampling was used to select second-year senior high school classes that offer a common subject, specifically elective mathematics. The study focused on circle theorems, a topic taught in Form 2 according to the senior high school core mathematics curriculum in Ghana. Certified professional teachers with undergraduate degrees in mathematics education and masters of philosophy in mathematics and mathematics education were recruited for this study. Teachers assigned to the treatment groups received training to use the learning package, while those in the control group underwent separate training to prevent interaction between them. The lessons were conducted by a mathematics teacher who received assistance and supervision from the researcher to ensure proper implementation of the prescribed procedures.

2.5. Sample Size Determination

The sample size for this study was calculated using the Yamane formula, which is appropriate for determining sample sizes in finite populations. The formula is expressed as follows:

$$n = \frac{N}{1 + N \cdot e^2}$$

Where:

n = sample size
N = population size
e = margin of error (expressed as a decimal)

2.6. Parameters

The following table summarizes the individual school populations, their respective proportions, and the calculated sample sizes:

Tabel 1 - Composition of the Sample Size Determination

School	Population	Population proportion	Sample size
A	351	0.485	95
B	373	0.515	101
Total	724	1.000	196

Total Population, $N = 724$ *(sum of Schools A and B)*
Desired Sample Size, $n = 196$

The populations for the individual schools were estimated to be 351 for School A, and 373 for School B, with corresponding sample sizes of 95, 101 respectively. This proportional allocation ensured that the total sample size of 196 was achieved, reflecting the distribution of populations across the schools involved in the study.

2.7. Pre-Test and Post-Test Design

A pre-test and post-test design was used to measure students' prior knowledge before the intervention and their academic achievement after the intervention. Pre-tests were conducted at the beginning of the study to establish baseline performance levels for both groups, while post-tests were administered at the end of the intervention to assess learning gains. This design allowed for statistical comparisons of student performance, ensuring that any observed differences could be attributed to the instructional strategies employed.

However, as the quasi-experimental design does not involve random assignment, there is a possibility of selection bias due to pre-existing differences between groups before the intervention (Janssen & Kollar, 2021). To account for this limitation, statistical techniques such as Mann-Whitney U test were employed to control for baseline differences between the experimental and control groups. Additionally, demographic and academic background variables were considered to minimize the influence of extraneous factors on the study's outcomes.

2.8. Ensuring Rigor in Data Collection and Analysis

To ensure the credibility and generalizability of the findings, data collection followed a systematic and structured approach. The pre-tests and post-tests were administered under standardized conditions, ensuring that all students had equal exposure to the assessment environment and that external variables were minimized. Strict adherence to consistent testing procedures helped maintain the integrity and reliability of the collected data.

The data analysis process incorporated both descriptive and inferential statistical methods to provide a comprehensive evaluation of student performance. Given the quasi-experimental nature of the study, the Mann-Whitney U test, a non-parametric statistical technique, was used to determine the statistical significance of learning gains between the experimental and control groups. This method was particularly suitable for analyzing differences in student achievement, as it does not assume a normal distribution of data and is robust for comparing independent samples in educational research.

Additionally, effect size calculations were performed to measure the magnitude of the instructional impact. Effect size provides a more practical interpretation of the results, offering insights into the educational significance of the intervention beyond statistical significance. By integrating these rigorous analytical techniques, the study ensured that conclusions drawn were valid, reliable, and applicable to broader educational contexts.

2.9. Validity and Reliability of Measurement Instruments

Ensuring that assessment instruments accurately measure their intended constructs is essential for the credibility and robustness of research findings. The instruments underwent validation through expert review and pilot testing to ensure content validity. The pre-test and post-test questions were carefully aligned with national mathematics curriculum standards and reviewed by a panel of mathematics education experts. The test items were designed to comprehensively assess students' conceptual understanding, problem-solving abilities, and application of circle theorems in a structured manner. A pilot study was conducted with students outside the study population to evaluate the clarity, appropriateness, and difficulty level of the test items. Based on the pilot study feedback, ambiguous or unclear questions were refined to ensure that the final assessment instruments were unbiased, clear, and aligned with the study's objectives.

To assess reliability, Cronbach's alpha ($\alpha = 0.85$) was calculated, indicating strong internal consistency (Cohen, Manion, & Morrison, 2018). Additionally, test-retest reliability was evaluated by administering the test twice to a small subsample of students at different time intervals. The high correlation coefficient between the two sets of scores confirmed the stability and reliability of the assessment tool over time.

3. Results and Discussion

3.1. Results

To determine whether to conduct a parametric or non-parametric test to establish significant differences between the groups, it is essential to perform a normality test. The normality assumption requires that the pre-test and post-test scores follow a normal distribution within each group. This study assesses normality using both statistical tests and visual representations.

Table 2 - Normality Test for Each Group

Tests	Group	Kolmogorov-smirnov		
		Statistic	df	P value
Pre-Test	Traditional	.114	101	.003
	Jigsaw with animation	.111	95	.005
Post-Test	Traditional	.106	101	.007
	Jigsaw with animation	.094	95	.036

a. Lilliefors Significance Correction

The results from Table 2 suggest that the data for both pre-test and post-test scores across the Traditional and the Integration of the Jigsaw with Computer Animation (Animation) do not meet the assumption of parametric method, with stronger deviations observed in the pre-test scores. Consequently, non-parametric statistical methods are more appropriate for analyzing the data to ensure robustness and validity of the findings. This consideration is particularly important given the reliance on accurate statistical interpretation to draw conclusions about the effectiveness of the instructional strategies under investigation.

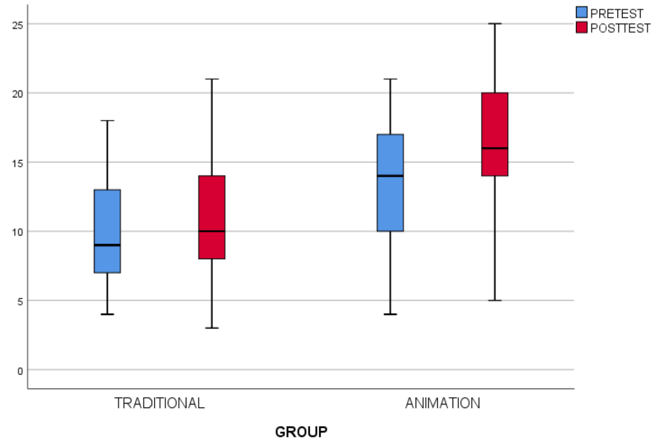

Figure 2. A Boxplot Showing Distribution of Students Achievement Across Groups

The box-plot in Figure 1 shows the pre-test and post-test score distributions for the Traditional and jigsaw with animation groups. Both groups improved from pre-test to post-test, with the jigsaw with animation groups showing a greater median increase. The Traditional group maintained a consistent interquartile range (IQR), indicating stable score distributions, while the jigsaw with animation group displayed a wider IQR in post-test scores, reflecting increased variability. This suggests that the jigsaw with animation method, while effective overall, had uneven impacts across students. These results highlight the need for robust statistical analysis, potentially using non-parametric methods, to accurately compare the effectiveness of the two instructional approaches.

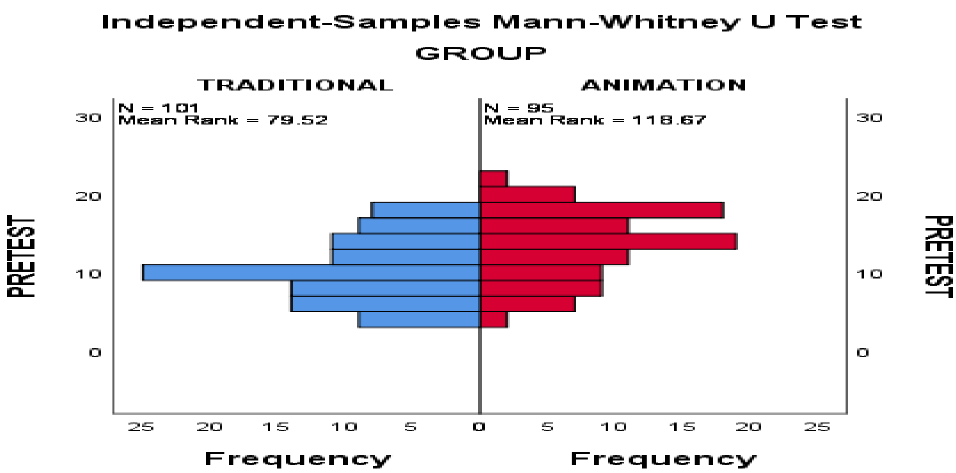

Figure 3. Impact of Teaching Method on Student Achievements Pretest scores

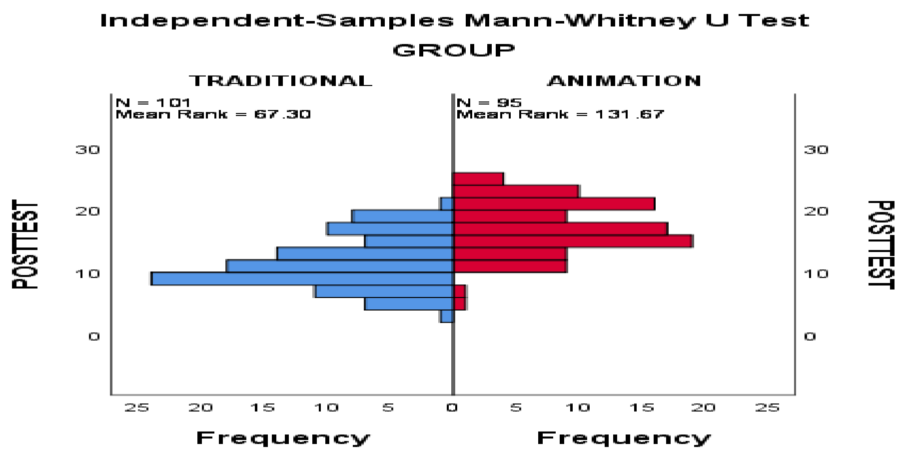

Figure 4. Impact of Teaching Method on Student Achievements: Posttest Scores

The histograms in Figures 2 and 3 show the distribution of pre-test and post-test scores for the Traditional and Jigsaw with Animation group, with results from the Independent Samples Mann-Whitney U Test. In the pre-test, the jigsaw with animation group had a higher mean rank (118.67) compared to the Traditional group (79.52), indicating better initial performance in the jigsaw with animation groups. By the post-test, the jigsaw with animation group still had a higher mean rank (131.67), showing a concentrated improvement in scores. These results suggest that the jigsaw with animation groups experienced more significant improvement, highlighting the potential effectiveness of animation in enhancing student performance compared to traditional methods.

Table 3 - Independent-Samples Mann-Whitney U Test for the Various Stages Across Groups

Test	Sample Size	Mann-Whitney U	Wilcoxon W	Test Statistic	Stand. Error	Stand. Test Statistic	Asy Sig. (2-sided test)	Effect size
Pretest	196	6714	11274	6714	396.012	4.839	<0.001	0.346
Posttest	196	7948.5	12508.5	7948.5	396.18	7.953	<0.001	0.568

The results of the Independent-Samples Mann-Whitney U Test for both the pretest and post-test scores indicate significant differences between the groups. For the pre-test, the Mann-Whitney U statistic is 6714.000 ($Z = 4.839$, $p < 0.001$), suggesting a significant difference in the distributions of scores between the two groups at baseline. The effect size for the pre-test is 0.346, which indicates a medium effect according to conventional guidelines. For the post-test, the Mann Whitney U statistic is 7948.5($Z = 7.953$, $p < 0.001$), further supporting that there are significant differences in post-test performance between the groups. The effect size for the post-test is 0.568, which is considered a moderate to large effect, indicating a more substantial difference in performance after the intervention. Both results show that the instructional methods used (Traditional vs. jigsaw with animation groups) led to significant changes in student performance, with the posttest showing a more pronounced difference than the pre-test. The effect sizes suggest that while the intervention had a meaningful impact on both groups, the effect was more substantial in the post-test, particularly for the group exposed to the instructional intervention. These findings underline the importance of exploring the specific educational techniques used and their implications for future instructional practices.

3.2. Discussion

This study examined the effects of integrating computer animation with the Jigsaw cooperative learning model on students' achievement in understanding circle theorems, a geometrically complex topic. The research compared post-test performance between two groups: one receiving traditional instruction and the other engaging in Jigsaw cooperative learning with animated content. Results revealed a significant difference between the groups, with the Jigsaw with Animation group outperforming the Traditional group. The Mann-Whitney U test yielded a U value of 7948.5 ($Z = 7.953$, $p < 0.001$) and an effect size of 0.568, indicating a moderate-to-large impact of the combined instructional approach on student achievement. These findings suggest that integrating animations into collaborative learning environments can significantly enhance students' conceptual understanding of geometry.

Several factors contributed to the experimental group’s superior performance. One key factor was the interactive and engaging nature of animated content, which provided dynamic visual representations of abstract mathematical concepts. According to Sweller’s (1988) Cognitive Load Theory, animations reduce cognitive overload by breaking down complex information into manageable visual components. This may explain why students exposed to animations within the Jigsaw framework demonstrated improved comprehension. Animated content enabled students to visualize geometric relationships—such as angle theorems and chord properties—in real time, reinforcing conceptual understanding and enhancing problem-solving skills.

These findings align with previous studies, including those by Liu et al. (2024) and Kenedi et al. (2019), which reported that animation-supported cooperative learning improves problem-solving abilities and knowledge retention. Additionally, the Jigsaw model's collaborative structure promoted peer interaction and active engagement. By requiring students to become experts in specific aspects of the topic and teach their peers, the model fostered deeper cognitive processing and reinforced understanding. Research by Hutapea (2022) and Astra et al. (2020) supports the notion that cooperative learning strategies, when combined with multimedia tools, enhance students' ability to internalize and apply mathematical concepts. Beyond instructional design, student motivation likely played a crucial role in learning outcomes. The integration of animations increased students’ interest and engagement, making learning more enjoyable and accessible. Prior research by Mohammadi et al. (2022) and Patta et al. (2024) indicates that multimedia tools create stimulating learning environments that enhance motivation, leading to greater effort and persistence in problem-solving activities.

These findings have important implications for educational practice. Given the positive impact of combining computer animation with cooperative learning, educators should integrate multimedia tools into instructional strategies to enhance student engagement and conceptual understanding. In mathematics classrooms, particularly in geometry, animations serve as powerful teaching aids that help students visualize and manipulate complex ideas in ways that static diagrams and traditional lectures cannot. Additionally, cooperative learning strategies like the Jigsaw model should be encouraged, as they promote collaborative problem-solving, improve communication skills, and foster deeper mathematical understanding. Research by Kwon and Capraro (2021) and Olamigoke (2021) highlights that multimedia tools are most effective when used in student-centered, inquiry-based learning environments where peer-discussion and application reinforce comprehension.

To maximize these benefits, schools and curriculum developers should provide training for teachers on implementing animation-enhanced cooperative learning strategies effectively. While this study demonstrated promising short-term academic gains, further research is needed to explore the long-term effects of using computer animations in cooperative learning environments. Longitudinal studies could assess whether students retain their improved understanding and problem-solving skills over time. Prior research by Chen et al. (2019) suggests that while technology-enhanced learning can lead to immediate academic improvements, it does not always sustain long-term interest in mathematics. Moreover, the effectiveness of animations may depend on their level of interactivity, complexity, and realism. Research by Zhao (2023) indicates that while highly interactive multimedia tools can enhance engagement, they may also introduce additional cognitive demands that hinder learning if not properly structured. Further investigation is needed to determine the optimal design of animations for mathematics instruction, particularly in topics requiring strong spatial reasoning. Another critical area for future research is the role of teacher facilitation in the Jigsaw with Animation approach. While the Jigsaw model emphasizes peer-led learning, teacher guidance in structuring discussions, guiding inquiry, and ensuring equitable participation is essential to its success. Studies by Janssen and Kollar (2021) show that cooperative learning is most effective when teachers actively scaffold discussions and monitor group dynamics. Future research should explore best practices for teacher involvement in animation-supported cooperative learning to ensure that all students benefit equitably. Additionally, investigating how different student demographics—such as gender, prior achievement levels, or cognitive styles—respond to this instructional method could provide valuable insights for tailoring cooperative learning interventions to diverse student populations.

This study contributes to the growing body of research advocating for multimedia integration in mathematics education. By demonstrating that Jigsaw cooperative learning combined with computer animation significantly enhances students' understanding of circle theorems, this research provides empirical evidence supporting the effectiveness of technology-enhanced, student-centered instruction.

4. Conclusions

The findings of this study demonstrate that integrating the Jigsaw cooperative learning model with computer animation significantly enhances students' understanding of circle theorems compared to traditional teacher-centered instruction. This combination of multimedia and cooperative learning provides a structured, engaging approach to mastering complex mathematical concepts. While animations facilitate cognitive engagement and improve visualization, the collaborative structure of the Jigsaw model plays a crucial role in motivating students, promoting active participation, and fostering deeper conceptual understanding. Statistical analysis reveals a moderate to large effect size, reinforcing the educational value of multimedia-integrated cooperative learning. These results align with existing research on cognitive load theory and multimedia learning, highlighting how visual tools simplify abstract concepts and make them more accessible.

Despite these promising outcomes, the study's scope was limited to short-term academic achievement within a specific educational setting. Future research should examine long-term retention of mathematical concepts using this approach. Additionally, studies could explore the impact of various animation types—such as interactive simulations, 3D visualizations, and augmented reality—to determine which forms of multimedia are most effective. Another crucial avenue for research is understanding individual learner differences, such as prior mathematical knowledge, cognitive processing styles, and spatial reasoning skills, in shaping the effectiveness of this method. Investigating these factors could lead to more targeted instructional interventions.

Beyond theoretical contributions, this study has practical implications for teachers, curriculum developers, and policymakers. Educators can enhance student engagement and comprehension by integrating structured peer-learning activities with multimedia-based instruction. This approach not only fosters collaboration and critical thinking but also develops essential skills for success in STEM fields. However, effective implementation requires adequate teacher training. Professional development programs should equip teachers with the skills to integrate animations effectively, ensuring that multimedia tools supplement rather than replace direct instruction. Future research should also examine the scalability of the Jigsaw-with-animation model across different educational levels and STEM subjects where visualization is critical. Exploring its effectiveness in teaching other mathematical topics—such as trigonometry, algebra, and calculus—could provide insights into its broader applicability. Additionally, studying the influence of classroom environments, school resources, and teaching styles on the success of this instructional method would further refine its implementation.

This research contributes to the growing body of evidence supporting multimedia-enhanced cooperative learning, particularly for complex mathematical concepts. It underscores the need for well-balanced instructional strategies that integrate pedagogy and technology, ensuring that multimedia tools enhance, rather than replace, the cognitive and social benefits of collaboration. Policymakers should support technology integration in classrooms by providing infrastructure, training programs, and research-based frameworks to guide effective implementation. Schools should invest in digital learning technologies, cooperative learning models, and professional development programs to create more engaging educational environments.

The combination of the Jigsaw cooperative model and computer animation has the potential to transform mathematics education and other complex subjects by fostering active participation, deeper conceptual understanding, and improved academic achievement. As education evolves, adopting innovative instructional strategies is essential to meet diverse student learning needs and create dynamic, effective learning experiences. Based on these findings, educators are encouraged to integrate animations into cooperative learning models like Jigsaw to enhance student engagement, comprehension, and retention—particularly when teaching challenging mathematical topics such as circle theorems. Future research should explore the long-term impact of this approach on student performance and investigate how demographics (e.g., gender, prior mathematics achievement) influence its effectiveness. Tailoring instructional strategies based on these insights can help optimize learning experiences for diverse students, preparing them for both academic success and real-world problem-solving.

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Conflict of Interest

The authors of this research state that they have no conflicts of interest with regard to its publication.

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