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RESEARCH ARTICLE

Pedagogical Benefits of Dynamic GeoGebra Software in Learning Tenth-Grade Circles

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ABSTRACT

This study investigates the pedagogical benefits of integrating Dynamic GeoGebra Software into tenth-grade circle geometry instruction. Through a comprehensive examination of students' proficiency in various geometric concepts, including circle definitions, circumference calculation, and understanding of chords, secants, and tangents, the study identifies areas of commendable mastery and moderate proficiency. It underscores the importance of targeted instruction to address specific challenges in geometry education, advocating for the incorporation of technology-driven approaches like GeoGebra. The integration of GeoGebra software is found to significantly enhance students' comprehension of circle geometry by facilitating visualization of geometric properties and fostering engagement, motivation, and collaboration among students. Despite encountering navigation and technical issues, the overall perception among participants is favorable towards the software's efficacy in improving learning experiences. However, the study reveals a weak and insignificant correlation between students' initial understanding of geometric concepts and their improvement through software integration, emphasizing the need for further optimization through tailored instruction and varied learning activities. The findings highlight the potential of technology-driven approaches like GeoGebra to positively transform geometry education, while also stressing the ongoing requirement for support and professional development to ensure effective technology integration in classrooms. Additionally, implementing a structured peer tutoring program focused on GeoGebra software usage is proposed as a means to address identified challenges and enhance students' overall learning experience in geometry.

INTRODUCTION

In the landscape of mathematics education, the integration of technology has emerged as a transformative force, offering new avenues for engaging students and enhancing pedagogical approaches (Hoyles, 2018). As the educational community strives to adapt to the evolving needs of learners, this study addresses a critical juncture in geometry education. Tenth-grade geometry serves as a foundational stepping stone, and the study recognizes the potential of dynamic GeoGebra software to reshape the learning experience in this crucial academic stage.

Traditional methods of teaching geometry often rely on static illustrations and abstract representations, posing challenges for students to visualize and internalize complex geometric concepts, particularly those related to circles (Vitale et al., 2014). GeoGebra, as a dynamic and interactive mathematical software, offers a promising solution by providing students with a platform to explore, manipulate, and visualize geometric relationships in real-time. This study aims to bridge the gap between traditional instructional approaches and the dynamic potential of technology, seeking to unravel the pedagogical benefits that arise when GeoGebra is incorporated into tenth-grade circle geometry lessons.

In our school, challenges arise from limited technology integration, insufficient teacher professional development, curriculum misalignment, low student engagement, and equity concerns. These issues hinder effective teaching and learning experiences, impacting student achievement and overall school performance. Addressing these challenges requires collaborative efforts to enhance technology infrastructure, provide comprehensive teacher training, align curriculum with student needs, promote student engagement strategies, and foster equity and inclusion in education. By addressing these gaps, we can create a more supportive and inclusive learning environment conducive to student success.

The research acknowledges the growing body of literature supporting the integration of technology in mathematics education, emphasizing the need for empirical evidence on the effectiveness of GeoGebra in enhancing both teaching strategies and student learning outcomes (Hohenwarter & Preiner, 2007). By focusing specifically on the intricate domain of circles within tenth-grade geometry, this study aims to contribute valuable insights to the broader discourse on technology-mediated education. As education systems worldwide grapple with the challenges of adapting to digital tools, understanding the specific benefits and challenges of GeoGebra in the context of circle geometry is pivotal for informing evidence-based instructional practices. The research aspires to provide educators, curriculum designers, and policymakers with nuanced insights that can inform future pedagogical decisions and contribute to the ongoing evolution of mathematics education in the digital age.

Theoretical Framework

This study explores the efficacy of employing dynamic GeoGebra software as a pedagogical tool to enhance the learning of circle geometry among tenth-grade students. The theoretical framework for this study draws upon several key theoretical perspectives.

Firstly, it integrates principles of constructivism, emphasizing the active construction of knowledge by learners through hands-on exploration and manipulation of geometric objects within the software environment (Vygotsky, 1978). GeoGebra's dynamic features allow students to interact with geometric figures, encouraging them to construct their understanding of circle geometry through experimentation and discovery.

Secondly, the framework incorporates the Technological Pedagogical Content Knowledge (TPACK) framework, which emphasizes the integration of technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK) in effective teaching with technology (Mishra & Koehler, 2006). TPACK provides a lens for analyzing how teachers' proficiency in using GeoGebra software intersects with their pedagogical and content knowledge to design meaningful learning experiences that facilitate students' understanding of circle geometry.

Additionally, the framework considers cognitive load theory, examining how GeoGebra's interactive features can support cognitive processing by providing visual representations and immediate feedback, thereby reducing cognitive load and promoting deeper understanding of circle concepts (Sweller, 1988). By synthesizing these theoretical perspectives, the study aimed to investigate the pedagogical benefits of dynamic GeoGebra software in enriching tenth-grade students' learning experiences and fostering a deeper understanding of circle geometry.

Conceptual Framework

The pedagogical benefits of Dynamic GeoGebra Software in geometry education revolve around the seamless integration of technology and pedagogical strategies within the learning process. At its core, the framework identifies Dynamic GeoGebra Software as a pivotal tool, offering an interactive platform that merges geometry, algebra, and calculus functionalities. This technology-driven environment is underpinned by pedagogical approaches that include active learning, visual representation, deductive reasoning, and problem-solving. The resulting benefits are threefold: comprehensive understanding is facilitated through real-time exploration and dynamic visualization of theorems; stimulated critical thinking arises from exploratory problem-solving and connections to real-world applications; and enthusiasm for mathematics is nurtured via engaging experiences and the visualization of abstract concepts. These pedagogical benefits, in turn, yield learning outcomes characterized by deeper conceptual understanding, enhanced critical thinking skills, and a positive attitude towards mathematics. In essence, the conceptual framework encapsulates the synergistic relationship between technology integration and pedagogical strategies in leveraging Dynamic GeoGebra Software to transform geometry education into a dynamic, interactive, and engaging learning journey.

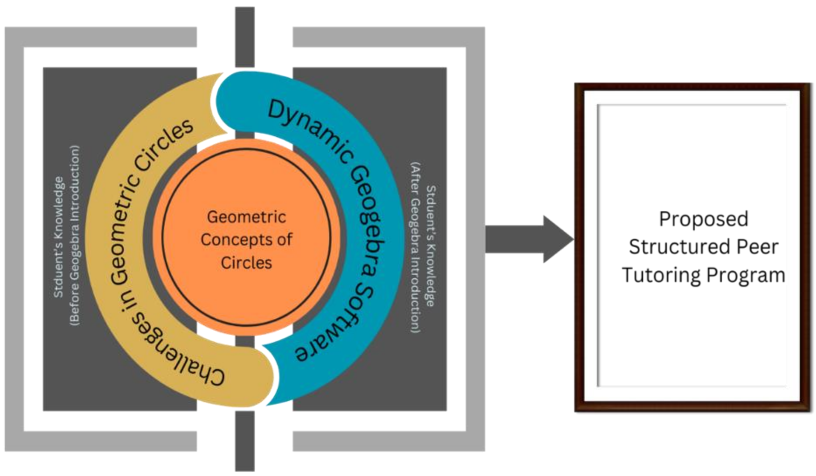

Figure 1. Schematic Diagram of the Study

METHODS

The study employed a descriptive-correlational research design to explore the impact of GeoGebra on pedagogy and student learning in geometry. Through survey questionnaires, data were collected to examine the relationship between students' understanding of geometric concepts and their improvement levels during the integration of Dynamic GeoGebra Software for Circles. Structured surveys, including Likert scales and closed-ended questions, were utilized for data collection, facilitating descriptive analysis. Conducted within Carmen District, including schools such as Carmen National High School, Manoligao National High School, Cahayagan National High School, and Vinapor National High School, the study's geographical context is essential. Located at varying distances from Butuan City, transportation primarily involves buses or jeepneys, with subsequent travel by tricycle to reach the respective schools. Understanding these logistical aspects aids in assessing student access and the educational infrastructure supporting the study.

The study targeted Grade 10 students and mathematics teachers from the aforementioned schools. Utilizing Cochran's formula and random selection methods, 209 students and 14 teachers were selected as participants. Each school section underwent a random selection process, ensuring equal opportunities for inclusion without bias. To enhance reliability, the research employed a structured self-administered questionnaire, pre-tested at FS Omayana National High School. Adjustments were made based on feedback, ensuring consistency and reliability, supported by Cronbach's alpha values. Additionally, pilot testing was conducted to assess validity, further strengthening the questionnaire's effectiveness.

Research approval and ethics clearance were obtained prior to data collection, emphasizing voluntarism and confidentiality. Quantitative data analysis involved scoring and quantification of responses, followed by descriptive-correlational techniques such as descriptive statistics and correlation analysis. Inferential statistics determined the significance of observed relationships, guiding the interpretation of results in the context of the research questions and objectives.

The study's findings contribute to understanding the pedagogical benefits of Dynamic GeoGebra Software in geometry education, providing insights into its impact on both pedagogy and student learning. Ethical guidelines were adhered to throughout, ensuring the integrity of the study and protecting participants' rights.

RESULTS AND DISCUSSION

Table 1 displays the level of students' understanding of geometric concepts in Circles. Students generally demonstrate a high understanding of geometric concepts related to circles, as evidenced by an overall mean score of 3.69. The results indicate a high level of proficiency in fundamental aspects such as defining a circle, identifying its center and radius, calculating its circumference, and understanding the relationship between its diameter and radius. Additionally, participants demonstrate a strong grasp of finding the area of a circle and understanding the properties of chords, secants, and tangents within a circle. However, there are certain areas where the participants' understanding is rated as moderate, suggesting room for improvement.

Table 1. Level of students' understanding of geometric concepts in Circles.

Indicator	Mean	Remark	Interpretation
1. I understand the definition of a circle.	4.16	High	Have a positive inclination toward the statement.
2. I can identify the center and radius of a circle.	4.08	High	Have a positive inclination toward the statement.
3. I know how to calculate the circumference of a circle.	3.88	High	Have a positive inclination toward the statement.
4. I understand the relationship between the diameter and radius of a circle.	3.89	High	Have a positive inclination toward the statement.
5. I can find the area of a circle.	3.87	High	Have a positive inclination toward the statement.
6. I know the properties of chords, secants, and tangents in a circle.	3.70	High	Have a positive inclination toward the statement.
7. I understand how to calculate the length of a chord.	3.49	Moderate	Lack of strong opinion or a state of indifference regarding the statement.
8. I can find the measure of an arc in a circle	3.54	High	Have a positive inclination toward the statement.
9. I know how to calculate the area of a sector in a circle.	3.22	Moderate	Lack of strong opinion or a state of indifference regarding the statement.
10. I understand the concept of inscribed and circumscribed circles.	3.07	Moderate	Lack of strong opinion or a state of indifference regarding the statement.
Overall	3.69	High	Have a positive inclination toward the statement.

Legend: 1.00 – 1.49 Very Low; 1.50 – 2.49 Low; 2.50 – 3.49 Moderate; 3.50 – 4.49 High; 4.50 – 5.00 Very High

Notably, calculating the length of a chord, determining the area of a sector within a circle, and understanding the concept of inscribed and circumscribed circles are highlighted as moderate proficiency areas. This aligns with contemporary research emphasizing the importance of providing targeted instruction to address specific areas of challenge in geometry education (Mukuka & Alex, 2024).

Additionally, recent studies advocate for incorporating technology-driven approaches, such as interactive software like GeoGebra, to enhance students' geometric reasoning and comprehension (Kangwa, 2022). Thus, educators can leverage these findings to tailor instructional strategies and utilize technological tools effectively to support students' mastery of circle-related concepts.

Table 2 displays the level of improvement in students understanding during the integration of Dynamic GeoGebra Software for Circles. The results overwhelmingly have a positive response regarding the use of GeoGebra software in enhancing understanding, engagement, visualization, motivation, and collaboration in learning geometric concepts related to circles. The mean scores for all indicators are notably high, with most falling within the "Very High" range with the mean score of 4.71. This indicates a strong consensus among respondents that GeoGebra software is highly beneficial for learning about circles.

Table 2. Level of improvement in students understanding during the integration of Dynamic GeoGebra Software for Circles.

Indicator	Mean	Remark	Interpretation
1. The use of GeoGebra software enhanced me understanding of geometric concepts related to circles.	4.84	Very High	Have a high level of agreement or a positive disposition toward the statement.
2. I found the activities with GeoGebra software engaging and interesting.	4.82	Very High	Have a high level of agreement or a positive disposition toward the statement.
3. GeoGebra software helped me visualize geometric properties of circles better than traditional methods.	4.84	Very High	Have a high level of agreement or a positive disposition toward the statement.
4. Using GeoGebra software increased my motivation to explore concepts related to circles.	4.72	Very High	Have a high level of agreement or a positive disposition toward the statement.
5. I felt actively involved in learning while using GeoGebra software for circles.	4.73	Very High	Have a high level of agreement or a positive disposition toward the statement.
6. GeoGebra software helped me grasp complex concepts in circles more effectively.	4.48	High	Have a positive inclination toward the statement.
7. I enjoyed experimenting with different geometric constructions using GeoGebra software.	4.79	Very High	Have a high level of agreement or a positive disposition toward the statement.
8. I found the interactive features of GeoGebra software helpful in understanding circle geometry.	4.63	Very High	Have a high level of agreement or a positive disposition toward the statement.

9. GeoGebra software encouraged me to collaborate with peers during circle geometry activities.	4.52	Very High	Have a high level of agreement or a positive disposition toward the statement.
10. I believe that using GeoGebra software improved my overall learning experience with circle geometry.	4.68	Very High	Have a high level of agreement or a positive disposition toward the statement.
Overall	4.71	Very High	Have a high level of agreement or a positive disposition toward the statement.

Legend: 1.00 – 1.49 Very Low; 1.50 – 2.49 Low; 2.50 – 3.49 Moderate; 3.50 – 4.49 High; 4.50 – 5.00 Very High

Specifically, respondents reported that GeoGebra software significantly improved their understanding of geometric concepts related to circles, made activities more engaging and interesting, enhanced visualization of geometric properties, increased motivation to explore circle concepts, facilitated active involvement in learning, helped grasp complex concepts effectively, allowed for enjoyable experimentation with constructions, and encouraged collaboration with peers during activities. According to (Zulnaidi & Syed Zamri (2017) found that the use of GeoGebra software led to significant improvements in students' understanding of geometric concepts and their engagement with mathematical tasks.

Moreover, students expressed that using GeoGebra software increased their motivation to explore concepts related to circles and encouraged collaboration with peers during geometry activities. These results suggest that digital tools like GeoGebra can foster a collaborative and exploratory learning environment, as supported by studies emphasizing the importance of collaboration in mathematics education (Radović et al., 2020). Overall, students believed that integrating GeoGebra software improved their overall learning experience with circle geometry, highlighting the potential of digital tools to positively impact mathematics education.

Table 3 displays the perceived extent of challenges by the students when incorporating Dynamic GeoGebra Software into geometry instruction. When incorporating Dynamic GeoGebra Software into geometry instruction, students perceived several challenges, as indicated by a mean score of 3.58 across various indicators.

Table 3. Perceived extent of challenges by the students when incorporating Dynamic GeoGebra Software into geometry instruction.

Indicator	Mean	Remark	Interpretation
1. I found it difficult to navigate the GeoGebra interface during geometry instruction.	3.63	High	Have a positive inclination toward the statement.
2. Understanding how to use GeoGebra commands and tools was challenging for me.	3.72	High	Have a positive inclination toward the statement.
3. Integrating GeoGebra software into geometry lessons created technical difficulties. (e.g., software crashes, connectivity issues)	3.55	High	Have a positive inclination toward the statement.
4. I faced challenges in transferring my geometric knowledge from traditional methods to digital platforms like GeoGebra.	3.76	High	Have a positive inclination toward the statement.
5. The pace of instruction with GeoGebra software was too fast for me to keep up.	3.67	High	Have a positive inclination toward the statement.

6. I encountered difficulties in interpreting geometric constructions and visualizations generated by GeoGebra.	3.73	High	Have a positive inclination toward the statement.
7. Collaborating with peers while using GeoGebra software posed challenges for me.	3.49	Moderate	Lack of strong opinion or a state of indifference regarding the statement.
8. I struggled to apply geometric concepts effectively within the GeoGebra software.	3.44	Moderate	Lack of strong opinion or a state of indifference regarding the statement.
9. Limited access to technology or devices hindered my engagement with GeoGebra-based geometry instruction.	3.25	Moderate	Lack of strong opinion or a state of indifference regarding the statement.
10. I found incorporating GeoGebra software into geometry lessons to be more challenging than traditional instruction methods.	3.62	High	Have a positive inclination toward the statement.
Overall	**3.58**	**High**	**Have a positive inclination toward the statement.**

Legend: 1.00 – 1.49 Very Low; 1.50 – 2.49 Low; 2.50 – 3.49 Moderate; 3.50 – 4.49 High; 4.50 – 5.00 Very High

Many students found it difficult to navigate the GeoGebra interface and understand how to use its commands and tools. This aligns with previous research suggesting that the usability of educational technology tools can impact student learning experiences (Ferri et al., 2020). Additionally, technical difficulties such as software crashes and connectivity issues were reported, highlighting the importance of robust technical support in implementing digital tools in education (Haleem et al., 2022).

Students also faced challenges in transferring their geometric knowledge from traditional methods to digital platforms like GeoGebra and interpreting geometric constructions and visualizations generated by the software. These findings underscore the need for scaffolding and explicit instruction to support students in making connections between different modes of learning (Kim & Hannafin, 2011).

Furthermore, limited access to technology or devices hindered engagement with GeoGebra-based geometry instruction emphasizing the digital divide as a barrier to equitable educational experiences (Warschauer & Matuchniak, 2018). Overall, students perceived incorporating GeoGebra software into geometry lessons to be more challenging than traditional instruction methods, highlighting the importance of ongoing professional development and support for teachers to effectively integrate technology into their pedagogy (Koehler & Mishra, 2019).

Table 4 displays the perceived extent of challenges by the teachers when incorporating Dynamic GeoGebra Software into geometry instruction. Teachers face challenges when incorporating Dynamic GeoGebra Software into geometry instruction, with an overall mean score of 4.47 across various indicators. They find it time-consuming to prepare and plan for integrating GeoGebra into lessons and struggle with understanding how to effectively use GeoGebra commands and tools for teaching geometry. This aligns with research highlighting the need for comprehensive professional development to support teachers in integrating technology into their pedagogy (Lawless & Pellegrino, 2007). Additionally, limited technical support and training resources exacerbate these challenges, indicating a need for ongoing support from educational institutions and technology providers (Ferri et al., 2020).

Table 4. Perceived extent of challenges by the teachers when incorporating Dynamic GeoGebra Software into geometry instruction.

Indicator	Mean	Remark	Interpretation
1. Integrating GeoGebra Software into geometry instruction requires a significant amount of time for preparation and planning.	4.21	High	Have a positive inclination toward the statement.
2. Understanding how to effectively use GeoGebra commands and tools for teaching geometry is challenging.	4.43	High	Have a positive inclination toward the statement.
3. Limited technical support or training resources are available to assist with incorporating GeoGebra software into geometry lessons.	4.29	High	Have a positive inclination toward the statement.
4. Adapting existing lesson plans to incorporating GeoGebra activities poses challenges for me as a teacher.	4.50	Very High	Have a high level of agreement or a positive disposition toward the statement.
5. Encountering technical issues such as software glitches or compatibility problems disrupts the flow of instruction.	3.71	High	Have a positive inclination toward the statement.
6. Ensuring all students have access to devices and technology needed to use GeoGebra software presents challenges.	4.93	Very High	Have a high level of agreement or a positive disposition toward the statement.
7. Creating meaningful and engaging GeoGebra-based activities that align with curriculum standards is challenging.	4.57	Very High	Have a high level of agreement or a positive disposition toward the statement.
8. Balancing the use of GeoGebra software with other instructional methods within limited class time is difficult.	4.50	Very High	Have a high level of agreement or a positive disposition toward the statement.
9. Supporting diverse learners' needs while using GeoGebra software for geometry instruction requires additional strategies and resources.	4.86	Very High	Have a high level of agreement or a positive disposition toward the statement.
10. I find incorporating GeoGebra software into geometry instruction to be more challenging than traditional teaching methods.	4.71	Very High	Have a high level of agreement or a positive disposition toward the statement.
Overall	4.47	High	Have a positive inclination toward the statement.

Legend: 1.00 – 1.49 Very Low; 1.50 – 2.49 Low; 2.50 – 3.49 Moderate; 3.50 – 4.49 High; 4.50 – 5.00 Very High

Adapting existing lesson plans to incorporate GeoGebra activities is particularly challenging for teachers, highlighting the importance of curriculum alignment and instructional design support (Johnson & Adams, 2019). Technical issues such as software glitches and compatibility problems disrupt the flow of instruction, underscoring the need for robust technical infrastructure and support systems in educational settings (Abubakar & Yunusa, 2024). Moreover, ensuring equitable access to devices and technology for all students presents a major challenge, emphasizing the digital equity issues that schools must address (Warschauer & Matuchniak, 2010). Overall, teachers perceive incorporating GeoGebra software into geometry instruction to be more challenging than traditional teaching methods, highlighting the need for comprehensive support and resources to facilitate effective technology integration in mathematics education (Koehler & Mishra, 2019).

Table 5 shows and presents the significant relationship between the level of student's understanding of geometric concepts and their level of student improvement of the students. As observed, level of student's understanding of geometric concepts was found to have no significant relationship with the level of improvement in students understanding of the students at α=0.05, with ρ_1=0.010, p=0.881. This result reveals that the level of understanding of the students of geometric concepts is not related to the level of improvement to the GeoGebra application.

Table 5. Significant relationship between the level of student's understanding of geometric concepts and their level of improvement.

Variable 1	Variable 2	Correlation Coefficient[a]	p-value	Relationship	Significance
Level of understanding	Level of improvement	0.010	0.881	Very weak and positive	Not significant

*Legend: [a] tested using Spearman's rho correlation test; -1.0 to -0.5 or 1.0 to 0.5 strong relationship; -0.5 to -0.3 or 0.3 to 0.5 moderate relationship; -0.3 to -0.1 or 0.1 to 0.3 weak relationship; -0.1 to 0.1 none or very weak relationship; *** significant at* $\alpha = 0.01$*;** significant at* $\alpha = 0.05$

The correlation analysis revealed a very weak and positive relationship (r = 0.010, p = 0.881) between the level of students' understanding of geometric concepts and their level of improvement in the classroom. This correlation was not found to be statistically significant. These findings suggest that while there may be a slight tendency for students with a better grasp of geometric concepts to exhibit higher levels of improvement, the relationship is not strong enough to draw meaningful conclusions. These results align with previous research by Pierce et al. (2007) who also reported a negligible correlation between students' understanding of mathematics and their improvement in learning activities. In contrast, a study by (Lipowsky et al., 2009) found significant association between students' comprehension of geometry and their classroom improvement levels. These consistent findings highlight the need for further investigation into the factors influencing student improvement in geometry education. The lack of a significant relationship between students' understanding of geometric concepts and their improvement through GeoGebra integration indicates the need to enhance the effectiveness of GeoGebra integration itself. This can be achieved through tailored instruction, varied learning activities, formative assessment, and collaborative problem-solving, ultimately optimizing students' learning experiences in geometry education.

Based on the results from Table 5, the integration of Dynamic GeoGebra Software in geometry education appears to have a significant positive impact on students' understanding of circles. The mean score of 4.71 indicates very high among students regarding the effectiveness of the software in enhancing their understanding of geometric concepts related to circles. Specifically, students reported that the use of GeoGebra software helped them visualize geometric properties of circles better than traditional methods, which suggests that the software facilitates deeper understanding of circle geometry. Additionally, the interactive features of GeoGebra were deemed helpful in understanding circle geometry, indicating that students appreciated the hands-on approach to learning facilitated by the software.

Moreover Awaji (2021) underscored the capacity of digital tools like GeoGebra to foster student engagement, aligning with the heightened interest and engagement observed among students during activities with GeoGebra software. This suggests that the software not only improves understanding but also enhances student and participation in geometry education. Overall, the integration of Dynamic GeoGebra Software appears to positively impact students' understanding of circles by enhancing visualization, facilitating interactive learning experiences, and fostering motivation and collaboration in geometry education.

CONCLUSION

In the realm of tenth-grade circle geometry instruction, integrating Dynamic GeoGebra Software offers several pedagogical advantages, as revealed by the study. Students demonstrate commendable mastery of fundamental concepts such as circle definitions, center and radius identification, circumference calculation, and diameter-radius relationships, providing a robust groundwork for further exploration. Moreover, they exhibit competence in more intricate topics like determining circle area and comprehending the properties of chords, secants, and tangents. However, certain areas, such as calculating chord length, circle sector area, and understanding inscribed and circumscribed circles, show moderate proficiency.

These findings underscore the importance of targeted instruction to address specific challenges, advocating for the integration of technology-driven approaches like GeoGebra. Implementing this software yields significant benefits in enhancing students' grasp of circle geometry. It not only improves visualization of geometric properties but also fosters engagement, motivation, and collaboration among students, despite encountering navigation and technical issues.

Nevertheless, the correlation analysis suggests a weak and insignificant link between students' initial understanding of geometric concepts and their progress through software integration. This highlights the need for further optimization of GeoGebra integration through tailored instruction and diversified learning activities. While emphasizing the potential of technology-driven approaches like GeoGebra to positively transform geometry education by enriching visualization, engagement, and collaborative learning experiences, the study also underscores the ongoing requirement for support and professional development to ensure effective technology integration in classrooms.

To address these challenges effectively, implementing a structured peer tutoring program centered on GeoGebra software in geometry instruction can be beneficial. This intervention encourages collaborative learning, enhances peer interaction, and offers targeted support to students grappling with software complexities. Leveraging peer expertise fosters a supportive learning environment conducive to enhancing proficiency with GeoGebra and improving overall geometry learning experiences.

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