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Improving students' geometric mathematical problems through the GeoGebra-assisted '5E' learning cycle

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ABSTRACT

In this quasi-experimental study, a pre-test and post-test control group design was employed. A cluster random sampling technique was used to select 25 seventh-grade students from each group. The research collected data on students' mathematical prior knowledge through objective tests conducted before the learning process. To assess the impact of the GeoGebra-assisted 5E learning cycle, an essay test was administered at the conclusion of the learning process. The statistical analysis, performed using a t-test, indicates that the GeoGebra-assisted 5E learning cycle has a significant positive effect on students' comprehension of mathematical concepts ($t = 16.50^*$ and $p = 0.0001$). These findings suggest the potential of the GeoGebra-assisted 5E learning cycle as an alternative and effective learning model to enhance students' understanding of mathematical concepts, thus addressing a critical need in mathematics education. This study not only contributes to the growing body of research on innovative teaching methods but also underscores the potential of technology-assisted education in improving students' mathematical comprehension. The implications of this research extend beyond the classroom, highlighting the importance of modern pedagogical tools and strategies for promoting mathematical understanding in today's educational landscape.

INTRODUCTION

Solving mathematical problems is a fundamental skill for students in the study of mathematics (Hendriana, Rohaeti, & Sumarmo, 2017). Central to mathematical learning is the mastery of problem-solving techniques that foster creativity, reasoning, critique, and systematic thinking (NCTM, 2000). As such, solving mathematical problems is a key learning objective (Surya et al., 2017). At the heart of mathematical knowledge lies the comprehension of mathematical concepts (Burhanzade & Aygör, 2014; Simon, 2017). Students can truly grasp mathematics when they understand its concepts and their significance (Simon, 2017). These concepts represent the necessary knowledge of specific mathematical relationships (Simon, 2017). Consequently, understanding previously learned knowledge necessitates recognizing these relationships, such as identifying prime numbers to understand finding factors (Bahr & Rieth, 1989; Simon, 2017).

Background problem and objectives

Dongmulwittayakom School, under the Kalasin Provincial Administration, reported an average score of 23.97 on the Ordinary National Educational Test (O-NET) for the 2021 academic year, falling below the national average. Regional and provincial averages were 26.04, 25.82, and 25.9,

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respectively. The mean score of 20.92, as assessed in geometric constructs, is indicative of poor performance. Geometry, a field with practical applications in daily life, deals with tangible, visually discernible content. By the seventh Grade, students are expected to possess a quantitative understanding.

The Study's Novelty and Research Problems: This study introduces the "5E" instructional model (Bybee, 1990), based on cognitive psychology and constructivist learning theory, with a focus on enhancing mathematical conceptual understanding in the context of geometry. This learning model comprises five stages: Engagement, Exploration, Explanation, Elaboration, and Evaluation (Duran & Duran, 2004). To optimize student learning and mathematical comprehension, the GeoGebra-Assisted "5E" Learning Cycle model is proposed (Plaikoil et al., 2019; Qawasmeh & Syouf, 2017; Yonwilad et al., 2022).

Understanding the importance

The study acknowledges the significance of mathematics conceptual understanding, particularly within geometry topics, as it forms a bridge between abstract mathematical learning and practical knowledge. Duval (1998) outlines the importance of three cognitive processes in learning geometry: visualization, construction, and reasoning. These processes are interdependent and vital to effective geometry learning. GeoGebra, a dynamic software encompassing geometry, algebra, and calculus, offers a multifaceted approach to mathematical learning, including visualization, construction, and interpretation (Adelabu et al., 2019; Ariawan, 2014). This collaboration between the GeoGebra-Assisted "5E" Learning Cycle model and GeoGebra is expected to enhance students' understanding of mathematical concepts and provide a bridge between abstract and concrete mathematical knowledge (Putri et al., 2021).

The clear and understandable research question

This study aims to answer how the "5E" learning cycle, assisted with GeoGebra, can improve students' ability to solve geometric mathematical problems and enhance their mathematical conceptual understanding. The research objectives include investigating the effectiveness of this teaching and learning approach and examining its impact on students' problem-solving skills and comprehension of mathematical concepts in a geometry context. The novelty of this research lies in its exploration of the synergistic effects of the "5E" learning cycle and GeoGebra on students' mathematical performance and conceptual understanding in the domain of geometry.

Rationale

The study recognizes the evolving role of technology in mathematics education, particularly in geometry, where visualization and exploration play a pivotal role in bridging the gap between abstract and concrete knowledge. The collaboration between the "5E" learning cycle and GeoGebra addresses the need for an innovative, student-centered earning model that leverages technology to enhance mathematical comprehension.

Significance of the study

The implications of this research extend beyond the classroom, highlighting the importance of modern pedagogical tools and strategies for promoting mathematical understanding in today's educational landscape. The study sheds light on the potential of technology-assisted education to improve students' mathematical comprehension and problem-solving abilities, addressing a critical need in mathematics education.

METHODS

Study design

The selected research methodology, which is a quasi-experimental design employing a pre-test and post-test control group design, seems well-suited for assessing whether a causal relationship exists between the independent variable, which is the GeoGebra-Assisted "5E" Learning Cycle, and the dependent variable, namely, the proficiency in mathematical problem-solving. This approach enables the comparison of outcomes between two distinct groups that have undergone differing instructional treatments (Creswell & Clark, 2011). This design is appropriate for examining causeand-effect relationships between the variables. A quantitative approach was adopted to analyze the final grades of students who experienced distinct educational interventions.

Location

The study took place at one of the Dongmulwittayakom schools affiliated with the Kalasin Provincial Administration. This location is specified, providing context for the research.

Target population

The study's target population encompassed all 7th-grade students within the school. To create a manageable sample size, a deliberate purposive sampling technique was employed, resulting in the selection of 50 students. This group was then evenly divided into two distinct categories: an experimental cohort and a control group, each comprising 25 students. The rationale for choosing high school students for the sample may be attributed to their introduction to formal problem-solving techniques. This decision was made with the intention of ensuring that both the experimental and control groups had comparable educational backgrounds. The purpose of adhering to this approach, as suggested by Pallant (2010), was to enable the application of parametric tests that evaluate the normality of class distributions. The aim was to ensure that both groups originated from similar educational backgrounds, facilitating a balanced and unbiased comparison in the study.

Data collection instruments

Mathematical Problem-Solving Test: Designed by the researcher, this tool was used to assess students' mathematical problem-solving skills. It was administered to both the experimental and control groups. In a 4-option multiple-choice test with 30 items, the assessment results showed that each test item had an Item-Objective Congruence (IOC) value ranging from 0.67 to 1.00. The analysis was conducted on a per-item basis, considering the level of difficulty, which ranged from 0.31 to 0.75, the Discrimination Index, which ranged from 0.25 to 1.00, and a confidence level of 0.87.

GeoGebra Program: This software application was integrated into the experimental treatment for students in the experimental group. However, additional information is required to understand how this program was incorporated into the learning process and its relationship with the GeoGebra-Assisted "5E" Learning Cycle.

GeoGebra-Assisted "5E" Learning Cycle: This constitutes the core of the experimental treatment, though the description provided is somewhat concise. More comprehensive details are necessary to grasp the specifics of this learning cycle, including its implementation, the components of each of the "5E" stages, and how it differs from the teaching method employed in the control group.

Data collection procedure

The data collection procedures are delineated, encompassing the administration of the pre-test (the mathematical problem-solving test) and the application of the GeoGebra program along with inquiry-based learning management for the experimental group. Nevertheless, the description could benefit from more specific information regarding the execution of these procedures.

Research variables

The research variables comprised the independent variable, the GeoGebra-Assisted "5E" Learning Cycle, and the dependent variable, which is the mathematical problem-solving abilities of the students. The experimental class included fifteen females and ten males, while the control class had eleven females and fourteen males. These two classes received disparate treatments: the experimental group was instructed to use the GeoGebra-Assisted "5E" Learning Cycle. In contrast, the control group followed a drill method without the incorporation of the GeoGebra-Assisted "5E" Learning Cycle.

Data collection techniques

A mathematical problem-solving test developed by the researcher was administered to assess students in both the experimental class (comprising 15 females and 10 males) and the control class (comprising 11 females and 14 males). These two groups received distinct treatments. The test lasted for one hour, and the scores were recorded; this test served as the pre-test.

The implementation of the GeoGebra program in the learning management of the experimental students, combined with inquiry-based learning (5E), where the researcher acted as the learning manager. It's important to note that this management spanned a total of 6 hours, and a control class followed a conventional teaching approach.

The implementation of the GeoGebra-Assisted "5E" Learning Cycle for the experimental students, again with the researcher serving as the learning manager. Similar to the previous approach, this management covered 6 hours of learning, while a standard control class received conventional instruction. A detailed learning cycle management plan for the GeoGebra-Assisted "5E" approach is presented in Table 1.

Figure 1 depicts the five steps of the "5E" learning cycle: Step 1: Begin a lesson by incorporating captivating scenarios or activities to engage students. Instructors can utilize questions to capture students' interest and guide them toward the learning objectives. Step 2: Exploration involves delving into the topics of interest, planning surveys, and collecting data through self-experimental practices. Step 3: Explanation includes the analysis of survey data and its transformation. The results are then summarized and communicated in various formats. Step 4: Elaboration entails applying the knowledge developed in collaboration with actual data or conclusions to describe other events or scenarios. Step 5: Evaluation is a learning assessment that gauges the student's level of understanding through critical thinking and model-based thought processes (Duran & Duran, 2004).

Before using mathematical problem-solving, analyze the data obtained from the test. Using the GeoGebra-Assisted "5E" Learning Cycle, compare students' ability to solve math problems before and after class. The independent samples t-test is used with statistical principles to determine the ability to solve problems from teaching and learning and then draw conclusions from research experiments and analyze the data obtained from the test. Compare the ability to solve mathematical problems after study with the 70% threshold using the GeoGebra-Assisted "5E" Learning, a statistical one-sample t-test with statistical principles, and find the ability to find problems from teaching and learning and then draw conclusions on research experiments. Analyze the data obtained from the satisfaction questionnaire. Compare the difference in mean for learning management using the GeoGebra-Assisted "5E" Learning with the threshold score of 70% criterion. The average level is based on the midpoint of the score at the end of learning. The satisfaction questionnaire in learning management improves students' mathematical geometry problems through learning cycles. GeoGebra-Assisted "5E" Students' responses to the GeoGebra-assisted "5E" consist of three areas that were measured using the Likert scale, with five expert responses. The query text is listed in Table 2 as Strongly Agree (SA), Agree (A), Undecided (U), Disagree (D), and Strongly Disagree (SD).

Post-test data underwent analysis through inferential statistics. To assess normality, the Shapiro-Wilk test was employed, considering a sample size greater than 0.50. The Levene test was utilized for assessing homogeneity. In cases where data exhibited normal distribution, the t-test was applied to identify average differences. The gain test was employed to evaluate the enhancement in students' mathematical problem-solving skills before and after the learning period. Processed gain data were derived from the variance between pretest and posttest scores in the experimental class.

Table 1. "5E" Learning Cycle

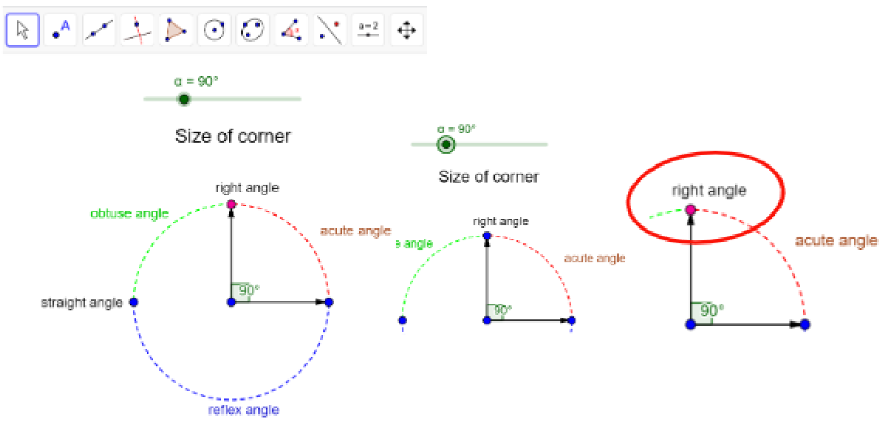
The GeoGebra-Assisted "5E" Learning Cycle	
Step1: Engagement	- Review your knowledge of basic geometric names. Teachers associate basic geometric knowledge with what is common in real life. By exploring and exemplifying things that have a component of a point. Sections of linear rays and angles, or see accompanying pictures, such as  Location points on the map
Step 2: Exploration	- The teacher lifts pictures from the activity, reviews previous knowledge, and then shares the characteristics of the primary geometry: points, straight lines, etc. What does a section of straight lines, rays, and angles look like for students to observe?  Location points on the map - The teacher assigns a point somewhere on the map, and then names it, such as a point "A" instead of the province. Mukdahan Point "B" represents Mahasarakham province for students to conclude. - Teachers use the GeoGebra program as teaching material on angles and types of angles. Show students an understanding that will help them develop spatial feelings and imagine angles.  - The teacher gives the student a worksheet titled Counting the number of straight lines. Then have the student draw a section of a straight line through a point, whereby the section of a straight line must consist of 2 points, and then record the number of straight lines and write the number of straight lines in the positive form of the count by the teacher as an example.

Table 1. Continued

The GeoGebra-Assisted "5E" Learning Cycle	
Step 3: Explanation	- The teacher summarizes the thoughts from the subject activity. Counting the number of straight lines, the number of lines formed by n points, where 1 line is only 2 points, is equal to 1+2+3+...+n-1, i.e. to create 5 points, there will be a total of 1+2+3+4 = 10 lines.
Step 4: Elaboration	- Students and teachers expand their knowledge of the dots. Straight line Sections of straight lines, rays, and angles using the "true dating puzzle" activity provide students with pictures of word cards. Then, have each student find their match.
Step 5: Evaluation	- Have students complete task 2 on basic geometry to check their understanding (give students time for task 2 on basic geometry before the next worksheet)

Table 2. Questionnaire of students' responses to the GeoGebra-Assisted "5E" Learning Cycle

No.	Points of opinion	Alternative Answers				
		SA	A	U	D	SD
1	Learning Management					
2	Contents					
3	Teachers					

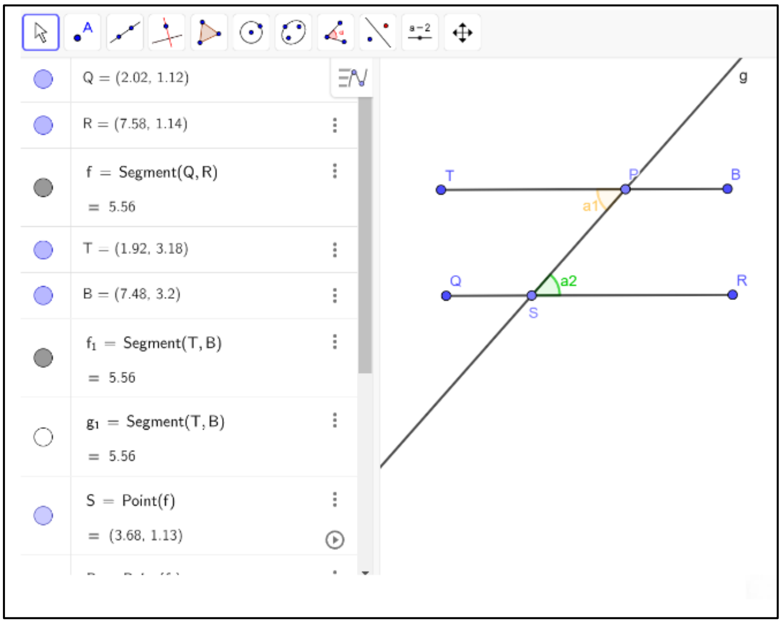


Figure 1. The student's post-test answer

FINDINGS

The research findings are derived from assessments, which involve subjective tests and observations of students' learning experiences using the GeoGebra-Assisted "5E" Learning Cycle. The assessment activities include subjective testing, where students are required to solve problems and find solutions. Figure 1 illustrates the manner in which students engaged with problem-solving steps within a constrained time frame.

Figure 2: Teaching and learning activities.

Figure 2 demonstrates the student's ability to comprehend the problem, establish connections among crucial facts, select a solution, and successfully solve the mathematical model. The GeoGebra-Assisted "5E" Learning Cycle execution, which is depicted in Figure 2

A common learning action is when students are asked to observe and learn the content presented on the projector, and it consists of five steps: In Step 1, engaging situations or activities are used to introduce engagement into a lesson. Instructors employ questions to spark students' interest, guiding them through the learning process. Step 2, exploration, involves understanding relevant issues and planning surveys for data collection through self-experimental practices. Step 3, explanation, focuses on analyzing survey data and its transformation. Step 4, elaboration, includes applying developed knowledge in collaboration with existing information or drawing conclusions to explain other events. Step 5, evaluation, is a learning assessment involving thought modeling activities to gauge the learner's knowledge level. This helps students and teachers comprehend and communicate learning objectives, assess students' abilities, and address challenges in problem-solving or learning difficulties within each group.

Based on the tests, the statistical value for the control classes was 7.50, and for the experimental class was 16.50, with a p-value of 0.000. The obtained result value indicates that the t-count is greater than the t-table, and the p-value is less than the specified error rate of 0.05. Consequently, the decision was made to reject the null hypothesis (H0), signifying a distinction in students' comprehension of mathematical concepts between the groups that learned using the GeoGebra-Assisted "5E" Learning Cycle.

Table 4 shows that post-test scores were statistically significantly higher than pre-test scores in preschool and post-school testing control classes and experimental classes at 0.05. To determine if the groups were equal, the independent samples t-test results are shown in Table 5. The table demonstrated that there was no statistically significant difference in the student's scores in the therapy student using a mastery learning approach through GeoGebra.

To assess the effectiveness of the GeoGebra-Assisted "5E" Learning Cycle as a mastery learning tool in geometry, an independent sample t-test was conducted. The comparison involved the consideration of students' scores in geometric and procedural knowledge. The post-test analysis utilized the GeoGebra-Assisted "5E" Learning Cycle mastery learning strategy as the independent variable, distinguishing between experimental and control groups based on the type of instruction. The instructional method had an impact on the post-test results, which focused on evaluating students' comprehension of geometry. The findings of the independent sample t-test are presented in Table 6.

Table 4: Pretest t-test Results pre-test and post-test

Groups	score	N	$\underline{x}$	SD	df	t	p
control classes	(Pre-test)	25	10.84	0.85	24	7.50*	.00001
	(Post-test)	25	15.52	0.79	24		
experimental classes	(Pre-test)	25	10.76	0.93	24	16.50*	.00001
	(Post-test)	25	19.04	0.73	24		

* p <.05

Table 5. Displays the outcomes of the independent samples t-test on the pre-test scores of both the experimental and control groups of students.

Groups	N	$\underline{x}$	SD	df	t	p
control classes	25	10.84	0.85	24	-0.135926*	.44651
experimental classes	25	10.76	0.93	24		

Table 6. Showcases the outcomes of the independent samples t-test for the overall post-test scores of students in the experimental and control groups, utilizing the GeoGebra-Assisted "5E" Learning Cycle.

Groups	N	$\underline{x}$	SD	df	t	p
control classes	25	15.52	0.79	24	12.754506*	.00001
experimental classes	25	19.04	0.73	24		

Table 7. The score of after-learning activities using the GeoGebra-Assisted "5E" Learning Cycle.

score	N	$\underline{x}$	SD	df	t	p
Post-test	25	19.04	0.73	24	9.03 *	.00001

* p <.05

On the GeoGebra-Assisted "5E" Learning Cycle post-test, the experimental group's students performed much better than the control group's students. This led to the inference that the utilization of GeoGebra and mastery learning in teaching geometry applications is significantly more impactful compared to teaching without these elements.

The emphasis of the GeoGebra-Assisted "5E" Learning Activities is on enhancing students' mathematical problem-solving skills, particularly after surpassing the 70 percent threshold. This determination was made through an analysis test, a simple linear regression test, and a conclusive assessment, with the detailed test results presented in Table 7.

It was found that the after-learning test met the 70 percent threshold. After the study, the test scores were significantly higher than the specified threshold at the.05 level, indicating that students' activities using the GeoGebra-Assisted "5E" Learning Cycle were statistically significant.

DISCUSSION

The investigation into the virtual 5E instructional framework, designed to enhance students' proficiency in solving mathematical problems and guiding them to achieve a targeted 70 percent overall score, yielded results aligned with the intended objectives. The success could be attributed to the structured nature of inquiry-based learning activities, allowing students to systematically engage in the problem-solving process. This aligns with the outcomes observed by Pinmun et al. (2015) and Tunnala et al. (2011), where students exhibited mathematical problem-solving skills surpassing the 70 percent threshold, potentially attributed to knowledge-based learning activities. Drawing from the theory of knowledge enhancement, the provision of activities that enable learners to construct knowledge themselves, rather than merely receiving information, contributes to the development of self-knowledge. This self-knowledge fosters understanding and the application of acquired knowledge to solve real-life problems (Dachakupt & Yindeesuk, 2014; Thangjai & Worapun, 2022; Weed-Schertzer, 2023). Teachers play a crucial role in facilitating the development of instructional activities, emphasizing collaboration, communication between students and teachers, management, sequencing, and enhancement of mathematics instruction. The instructional framework involves specific steps: Step 1 aims to boost interest using tools such as games. Step 2 involves exploration, reviewing, and utilizing digital tools like the GeoGebra program. Step 3 includes explanation and conclusion, presenting findings in various formats. Step 4 expands understanding with tools like diverse teaching materials. Step 5 entails evaluation, incorporating homework assignments to enhance efficiency. This approach seeks to make learning mathematics more engaging, less monotonous, and enjoyable (Maulana et al., 2022).

In this stage, the value of visuals in mathematics learning is stressed. GeoGebra is a dynamic, interactive learning tool that can help students understand a mathematical idea better (Dahal et al., 2022; Hayati & Ulya, 2022; Negara et al., 2022; Saralar-Aras, 2022). Dynamic geometry environments provide tools for the representation and manipulation of geometric objects, as discussed by Adelabu et al. (2019) explain that these distinct contexts give learners a variety of opportunities to use geometrical objects and their procedures. Also, the environment may help students see different sides of several characteristics and theorems. Incorporating GeoGebra into education, especially in the context of geometry learning, has several benefits, including (1) producing geometric visualizations more quickly and accurately than with a pencil or ruler. Calibration errors are thus eliminated, and geometry lessons for children are simplified (Baidoo et al., 2022; Korkmaz & Yilmaz, 2022). (2) The animation features and manipulation tools in the GeoGebra program may help students better understand geometry (Uwurukundo et al., 2022). (3) The feedback offered assists students in confirming their comprehension. (4) It encourages students to investigate or showcase the attributes of a geometric item (Muzaini et al., 2023).

Multiply a geometry object. In the Explain phase, students are encouraged to validate and elucidate their ideas, compare their reasoning with peers, and incorporate concepts from their exploratory findings into their explanations. Consequently, the synergies among these three phases can enhance the conceptual understanding indicator, specifically the ability to articulate concepts in a sentence. The "Explore and Explain" step aids students in refining their ability to name ideas or provide examples. In subsequent, more complex steps, they apply their acquired knowledge by tackling practice questions. The reinforcement of concepts in various contexts or applications related to fundamental ideas aids in embedding them in long-term memory. Moreover, it is crucial for students to apply their knowledge and assess their comprehension. The evaluation stage not only allows teachers to assess student progress towards learning objectives but also encourages students to reflect on their knowledge and skills.

This research demonstrated that the incorporation of interactive multimedia in learning enhances students' comprehension. The GeoGebra-assisted 5E Learning Cycle minimizes traditional lecture-based instruction, providing students with more opportunities to collaboratively construct their understanding within group settings. The approach encourages students to actively seek out concepts independently through teacher-designed learning experiences. This is further supported by the assistance provided during the GeoGebra-assisted 5E Learning Cycle and field observations throughout the learning process, contributing to a dynamic learning environment. Student engagement is heightened, with increased questioning observed in both group settings and formal discussions, showcasing a greater willingness to express opinions. As per NCTM (2014), students develop quantitative understanding and reasoning skills by utilizing mathematical tools and technology as essential resources while effectively communicating their mathematical reasoning. Additionally, these tools facilitate the concrete representation and visualization of abstract mathematical concepts, promoting efficient instruction and meaningful learning when applied appropriately.

In the GeoGebra-Assisted "5E" Learning Cycle, students are entrusted with full responsibility for learning activities, providing them with opportunities to enhance their actions and mindset in the most effective manner. The flexibility of pupils in exploring topics, however, is typically restricted by traditional learning approaches. In contrast to the search process and knowledge building, traditional learning has up until now placed more emphasis on the act of receiving knowledge. Because of this, students who use the GeoGebra-Assisted "5E" Learning Cycle understand what they've already learned better than those who use traditional learning methods. Students' prior knowledge is one of the internal elements influencing their learning process because it might indicate how prepared they are to retain information. Preexisting knowledge serves as a prerequisite acquired before students engage in a learning activity, as it is considered relevant information existing at the commencement of learning a particular subject. This prior knowledge acts as a mental anchor for assimilating new information and forms the fundamental basis for conceptualization and skill development.

The findings of this study suggest that the conceptual comprehension discrepancies between the control and experimental groups continue even after correcting for the students' previous mathematics knowledge scores. This implies that the learning process facilitated by the GeoGebra-Assisted "5E" framework, regardless of the level of prior knowledge kids have, continues to affect how well they learn mathematical topics. The average score for the comprehension of mathematical concepts among students in the experimental class was 19.04, surpassing the control group's average understanding of 15.52, even after adjusting for the controlled prior knowledge score. The consistent positive impact of the GeoGebra-Assisted "5E" Learning Cycle on students' conceptual understanding is evident in the average difference in comprehension scores between the experimental and control groups. This effectiveness can be attributed to the constructivist learning approach, which encourages students to actively engage with the topic through multiple learning phases, each serving a specific function and contributing to the development of a more profound understanding of mathematical concepts.

CONCLUSIONS

The outcomes of the research carry significant implications for advancing mathematical learning. The GeoGebra-assisted 5E Learning Cycle emerges as a valuable model for enhancing students' understanding of mathematical concepts. To maximize its effectiveness, educators should carefully select activities and materials, create engaging lesson plans, and ensure they are suitable for students' cognitive abilities. Additionally, this study underscores the importance of foundational computer skills for both teachers and students, emphasizing the need for math educators to receive training in dynamic computer software to enhance teaching and learning.

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