Journal of Instructional Mathematics
E-ISSN 2722-2179

DOI: 10.37640/jim.v5i2.2173
Volume 5, Issue 2; 2024

Teaching Trigonometry Based on Realistic Mathematics Education and Game-Based Learning Approach

Nguyen Tien Da*, **Do Diep Anh, Pham Thi Chau Giang, Phung Phuong Dung, Dang Bui Khanh Linh**
Faculty of Pedagogy, Hanoi Metropolitan University, Vietnam
*ntda@hnmu.edu.vn

Article Info

Received
November 13, 2024

Revised
December 20, 2024

Accepted
January 14, 2025

Keywords

Game-Based Learning; Realistic Mathematics Education; Trigonometry; Understanding.

Abstract

Trigonometry, often perceived as abstract and challenging, can hinder its potential to equip students with crucial mathematical skills. We propose a novel approach—"RME-GBL"—integrating Game-Based Learning (GBL) through engaging games with Realistic Mathematics Education (RME) for contextualized learning. This study investigates the combined impact of GBL and RME on 9th graders' understanding and problem-solving abilities in trigonometry. This study assesses the effectiveness of "RME-GBL" in enhancing conceptual understanding and problem-solving skills compared to traditional methods by employing a pre-test/post-test design with a control group. After the treatment applied in the experiment, the student learning group (N=30) with RME-GBL experienced an improvement in conceptual understanding and problem-solving skills, with their average scores significantly differing from the control group, indicating the effectiveness of the applied method or intervention. The results also showed that students in the RME-GBL group were more confident, more engaged, more motivated, and had a better conceptual understanding compared to traditional teaching methods. This research holds the potential to unlock new avenues for making trigonometry learning more captivating and effective for 9th graders.

How to Cite:
Da, N. T., Anh, D. D., Giang, P. T. C., Dung, P. P., Linh, D. B. K. (2024). Teaching Trigonometry Based on Realistic Mathematics Education and Game-Based Learning Approach. *Journal of Instructional Mathematics*, *5*(2), 168-179.

INTRODUCTION

Problem-solving, a crucial skill involving the integration of past knowledge and its application to novel situations, requires sustained visualization within working memory (Mayer, 2001). Enhancing problem-solving performance is a key focus in cognitive psychology (Montague et al., 2014). Geometry education in middle school is pivotal in fostering spatial reasoning and geometric intuition, which are crucial for both academic and future mathematical success (Krawec, 2014).

The 2018 Vietnamese Mathematics Curriculum emphasizes experiential learning, advocating for ample opportunities for exploration, practice, and active engagement in rich mathematical activities (Tran et al., 2020). This aligns with the embodied cognition theory, which posits that cognitive processes are deeply rooted in physical interactions (Wilson, 2002). Embodied mathematics theory further emphasizes the importance of dynamic interactions, such as manipulating objects and engaging in hands-on activities, in forming enriched mental representations for effective mathematical learning (Giardino, 2018; Novak & Schwan, 2021; Pouw et al., 2014).

Cognitive science supports the idea that multisensory experiences enhance learning and memory formation (Hutmacher & Kuhbandner, 2018). GBL capitalizes on this by incorporating elements of play into the educational process, encouraging active engagement and motivating students through a cycle of 'fail, reflect, repeat.' GBL encompasses a variety of strategies, from board games to simulations, and aims to integrate game principles into core learning experiences. The wealth of research on GBL suggests that this is a growing field (Pesare et al., 2016). Researchers are actively seeking scientific evidence to demonstrate the effectiveness of this approach and exploring new applications in education. Games can be used as a motivating learning medium for students. Games can cause the generation that plays them to have a different way of thinking from the generation that does not play them because games can create their own learning styles. Those who play games have a more creative way of thinking. Games that are used as learning media are called educational games (Hasanah & Andayani, 2022). In line with the opinions of experts, this recreation-based learning influences coaching and learning techniques. In addition to being fun for students, total recreation-based learning also allows students to solve problems. This is closely related to the essential questioning ability of students.

The RME approach is one solution to overcome the problem of students' difficulties in understanding trigonometry material. The RME approach is a didactic approach or theory in teaching specifically for mathematics first established in the Netherlands, the characteristics of the RME approach involve many people in its development, namely Mathematics Teachers, school counselors, and also book writers (Zolkower et al., 2020). In general, the understanding of the RME approach is a problem presented to students that comes from the real world, but also the fantasy world of fairy tales or the formal world of mathematics, as long as these problems are truly real in the minds of students (Van den Heuvel-Panhuizen & Drijvers, 2020). RME aims to enable students to apply mathematical knowledge (Trung et al., 2019). RME, an educational theory, emphasizes learning through real-world contexts and student-centered exploration (Habsah, 2017; Sumirattana et al., 2017; Yuanita et al., 2018). Research has demonstrated the effectiveness of RME in improving student engagement, mathematical competence, and higher-order thinking skills, including problem solving and critical thinking. This study aims to determine the impact of a combined approach on students' geometry learning outcomes..

Geometry, a fundamental subject, often presents challenges in developing abstract concepts (Hosseini et al., 2022). This study investigates the effectiveness of a novel approach combining the GeG-Game model (integrating GeoGebra software with GBL) and RME (is called for short GeG-Game-RME) in teaching geometry to 9th-grade students in a Vietnamese public school.

This study investigates whether the GeG-Game-RME approach, utilizing concrete materials and teacher guidance, is a necessary prerequisite for effective geometry learning in middle school. While its impact remains debated, particularly for older students, this research gap needs further investigation. Complicating this issue is the lack of consensus on the definition and assessment of mathematical ability. However, the academic level correlates with math proficiency. Therefore, this study considers academic level better to understand the nuanced impact of the GeG-Game-RME approach. Specifically, this study addresses the key research question (RQ): Does the GeG-Game-RME model enhance middle school students' geometry understanding and problem solving?

RESEARCH METHODS

We conducted a pilot study to evaluate the effectiveness of the model. The study involved 9th grade students (N=30) from a public school in Vietnam. The students were randomly assigned to either the experimental group or the control group.

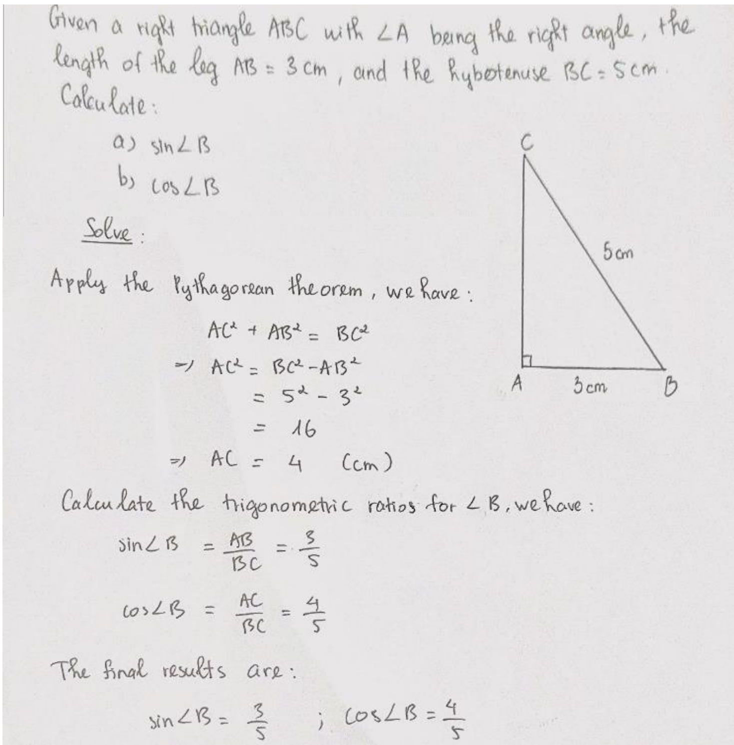
The control group received instruction using traditional methods and problem-solving exercises. With the traditional teaching method, the teacher plays a central role, actively imparting knowledge to students. The teacher directly presents the theory, concepts and definitions of trigonometric ratios, through the combination of illustrations on the board. Accordingly, the teacher selects a sample problem and guides students to apply the theory and formulas to solve the problem. The problem solving process is presented in detail, thereby forming a clear and accurate problem solving process for students. Next, students are assigned to solve similar exercises to practice and practice skills. Teachers often give quick tests in class and use short exercises to consolidate knowledge. However, this method mainly focuses on imparting knowledge and practicing problem solving skills, with little encouragement for students to explore, think creatively or make connections to reality (see Figure 1).

The experimental group received instruction using the GeoGebra-Game model and RME approach. Trained teachers facilitated the GEG-Game-RME activities in the experimental group. The instruction lasted for 4 weeks within the regular geometry curriculum. During this time, the students in the experimental group participated in a variety of GeoGebra-based games and activities. The games and activities were designed to help students learn the following geometric concepts: (1) points, lines, and planes; (2) angles; (3) triangles; (4) quadrilaterals; (5) circles.

Both groups will have similar mathematical ability levels based on a pre-test. At the end of the instruction period, all students were given a pre-test and a post-test to assess their understanding of geometric concepts. The pre-test and post-test were designed to be equivalent in terms of difficulty and content.

Illustration

Practice measuring the height of targets that cannot be approached and determining angles based on the sides of a right triangle (grade 9) https://www.geogebra.org/m/hmexuypg.


Given a right triangle ABC with $\angle A$ being the right angle, the length of the leg $AB = 3$ cm, and the hypotenuse $BC = 5$ cm.
Calculate:
a) $\sin\angle B$
b) $\cos\angle B$

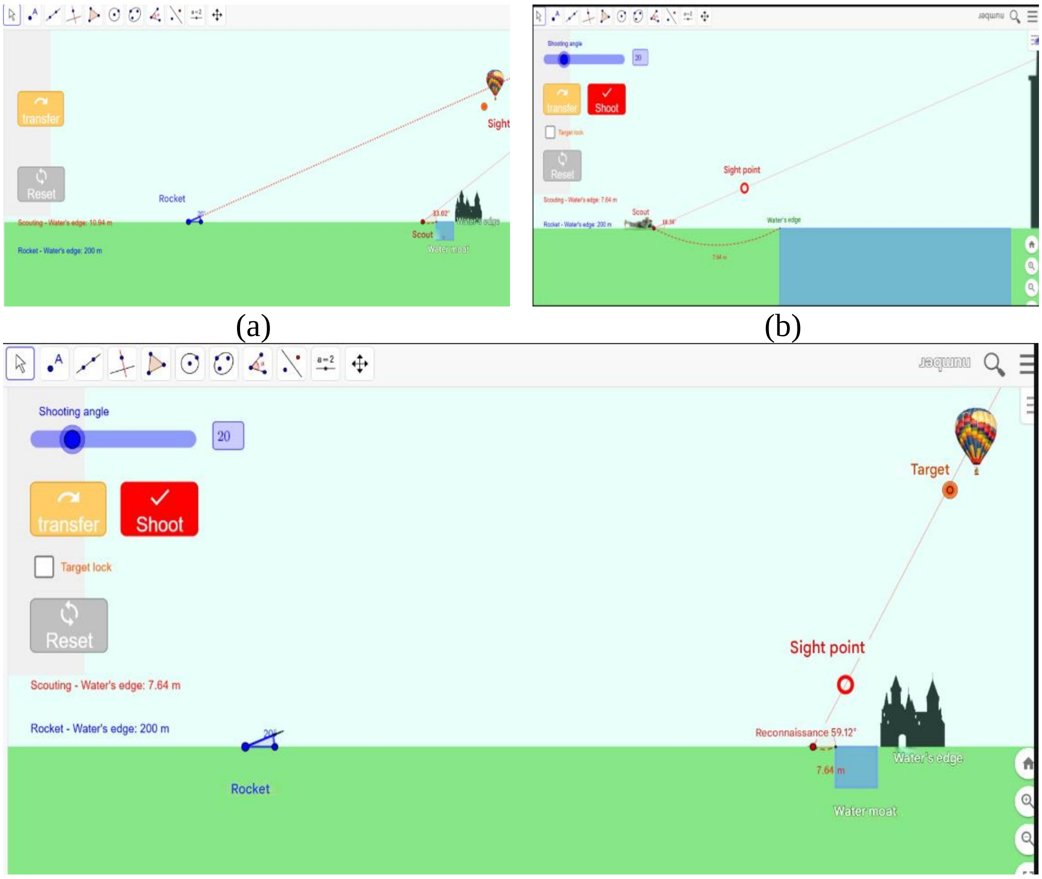
Solve:
Apply the Pythagorean theorem, we have:
$$AC^2 + AB^2 = BC^2$$
$$\Rightarrow AC^2 = BC^2 - AB^2 = 5^2 - 3^2 = 16$$
$$\Rightarrow AC = 4 \text{ (cm)}$$
Calculate the trigonometric ratios for $\angle B$, we have:
$$\sin\angle B = \frac{AB}{BC} = \frac{3}{5}$$
$$\cos\angle B = \frac{AC}{BC} = \frac{4}{5}$$
The final results are:
$$\sin\angle B = \frac{3}{5} \quad ; \quad \cos\angle B = \frac{4}{5}$$

Figure 1. Products of Control Class Students

Problem: (1) "Scout" can move close to the "Moat" but cannot cross the "Moat" (see Figure 2(a)); (2) "Scout " determines the distance from his position to the "Water's Edge" (see Figure 2(b)); (3) The "rocket" needs to know information about the target's altitude to determine the appropriate firing angle (see Figure 2(c)). Here is an example of the GeoGebra-Game-RME Model.

Implementation

The control group received traditional geometry instruction through lectures, textbook exercises, and expository demonstrations, in contrast to the experimental group, which followed the GEG-Game-RME approach. The GEG-Game-RME intervention spanned a specified timeframe (e.g., 4 weeks) within the regular geometry curriculum, with trained teachers facilitated the GEG-Game-RME activities in the experimental group. Students engaged in geometry lessons using the GEG-Game-RME approach, which integrated GBL and RME to make abstract concepts more tangible. They utilized GeoGebra, a dynamic geometry software, to visualize and manipulate geometric concepts interactively. Through game-based activities, students applied mathematical ideas to real-world scenarios, enhancing their problem-solving skills in an engaging way. Additionally, they worked collaboratively on exploratory tasks, discussing different strategies, analyzing their solutions, and improving their understanding through active participation and communication. In more detail, GEG-Game-RME implemented the following five phases.



(a) (b)

(c)

Figure 2. Model GeoGebra Game-RME

Phase 1: Introduction and Background Knowledge (Teacher-Led)

In this phase, the teacher guided the students through an engaging introduction to set the context for learning. The lesson began with the teacher presenting a scenario featuring Scout, the Moat, Water’s Edge, and the Rocket to capture students' interest. The teacher then explained the key challenges and learning objectives: (1) Scout approached the Moat but could not cross it; (2) Scout needed to determine the distance to the Water’s Edge; (3) The Rocket required a target altitude to calculate the firing angle. To ensure students were prepared for problem-solving, the teacher reviewed relevant mathematical concepts, including measurement, angles, and trigonometry (if applicable). This structured introduction helped students understand the problem scenario.

Phase 2: Brainstorming and Exploration (Student-Centered)

At this stage, the teacher facilitated a brainstorming session to encourage critical thinking and active participation. The teacher posed key guiding questions to help students analyze the problem: (1) How could Scout determine the distance to the Water’s Edge without crossing the Moat?; (2) What information could Scout gather to solve this problem?; (3) How could the Rocket use Scout’s data to calculate the correct firing angle?

Students were then encouraged to share their ideas, discuss possible approaches, and propose solutions. The teacher guided the discussion, ensuring that students considered various strategies while fostering creativity and diverse problem-solving methods. Through this interactive session, students built a deeper understanding of the mathematical principles involved in the scenario.

Phase 3: Guided Analysis and Model Building (Teacher-Led with Student Participation)

In this phase, the teacher introduced different mathematical methods that students could use to solve the problem. These methods included: (1) Similar triangles to determine distances indirectly; (2) Trigonometric functions (if applicable) to calculate angles and distances; (3) Other relevant mathematical tools that could aid in problem-solving. To support students' understanding, the teacher guided them in applying these methods step by step to the given scenario. Visual aids, such as diagrams, sketches, and real-world analogies, were used to help students visualize the relationships between different elements, making abstract concepts more tangible.

Students actively participated by performing calculations, interpreting results, and constructing a conceptual model to solve the problem. The teacher encouraged discussion, helped clarify misunderstandings, and ensured that students connected the mathematical concepts to the real-world scenario.

Phase 4: Application and Practice (Student-Centered with Teacher Support)

In this phase, students actively applied the chosen mathematical methods and models to solve practice problems with different distances and conditions. They worked individually or in small groups to reinforce their understanding by tackling variations of the original problem.

As students worked through the exercises, the teacher provided guidance and support, helping them identify and address any difficulties they encountered. The teacher encouraged students to: (1) Analyze their mistakes and understand where their reasoning might have gone wrong; (2) Refine their approach by adjusting calculations or reconsidering problem-solving strategies; (3) Discuss their findings with peers to develop a deeper conceptual understanding.

This hands-on practice allowed students to strengthen their problem-solving skills, build confidence in applying mathematical concepts, and develop a more flexible approach to tackling real-world mathematical challenges.

Phase 5: Consolidation and Reflection (Teacher-Led)

In this final phase, the teacher helped students consolidate their learning by reviewing the key concepts, methods, and solutions they had explored throughout the lesson. The teacher then facilitated a class discussion, encouraging students to reflect on their problem-solving experience: (1) What challenges did they face while solving the problem?; (2) How did they overcome those challenges?; (3) What lessons did they learn that could be applied to future problems?

Students were given the opportunity to share their reflections, ask questions, and provide feedback on the learning process. They also suggested improvements for tackling similar problem-solving scenarios in the future.

By the end of this phase, students had a deeper understanding of the mathematical concepts applied and how they could use them in real-world contexts. This reflection helped reinforce learning and encouraged a growth mindset in approaching complex problems.

Data Collection and Analysis

Data collection involved multiple techniques to ensure a comprehensive analysis of students' learning outcomes and experiences. Pre-tests and post-tests were administered to both the experimental and control groups using standardized geometry problem-solving assessments before and after the intervention to measure students' progress. Classroom observations were conducted to gather qualitative data on student engagement, problem-solving strategies, and interactions during lessons. Additionally, individual interviews with students from both groups provided deeper insights into their experiences and understanding of geometry concepts, allowing researchers to explore students' perspectives beyond quantitative test results.

Data quantitative analysis was conducted using both descriptive and inferential statistical methods to compare the performance of the experimental and control groups before and after the intervention. Descriptive statistics, including mean, median, standard deviation (SD), minimum, and maximum scores, were used to summarize the students' performance in the pre-test and post-test. The Shapiro-Wilk test was applied to assess the normality of the data distribution, revealing that pre-test and post-test scores in both groups deviated from normality (p-value< 0.05 in some cases). Given these results, both parametric (independent t-test) and non-parametric (Mann-Whitney U test) tests were conducted for group comparisons. Data from interviews will be analyzed using thematic analysis to identify emerging themes and patterns.

RESEARCH RESULTS

Data from the pre-test and post-test will be analyzed using independent samples t-tests to compare problem-solving scores between the experimental and control groups.

Table 1. Descriptive Statistics and Normality Analysis Result

Group	N	Mean	Median	SD	Min.	Max.	Shapiro-Wilk	
							W	p-value
Pre-test								
Experiment	35	6.09	6.00	1.03	4.00	8.00	0.935	0.040
Control	34	6.12	6.00	1.11	4.00	8.00	0.926	0.024
Post-test								
Experiment	35	7.26	7.50	1.15	5.00	9.00	0.940	0.056
Control	34	6.29	6.00	1.24	4.00	8.50	0.922	0.019

Table 1 shows slightly different average pre-test scores of 6.09 in the experimental class and 6.12 in the control class, both groups scored a median of 6.00. Furthermore, Shapiro-Wilk normality tests yielded p-values<0.05 for both groups, indicating non-normal distributions. Subsequent Mann-Whitney U tests revealed a p-value of 0.946 (see Table 2), exceeding the significance level of 0.05. This leads to accepting the null hypothesis (H_0): there is no statistically significant difference in the learning outcomes of the experimental and control groups (i.e., both medians are 6.0). Before the experiment's intervention, the learning performances of both groups were statistically equivalent.

Table 2. Independent Sample *t*-test results

Data	Mann-Whitney *U*		Difference
	Statistics	*p*-value	
Pre-test	589	0.946	No significant
Post-test	345	0.002	Significant

Post-test results in Table 2 revealed a noticeable difference between the experimental and control groups. While the control class averaged 6.29 and had a median of 6.00, the experimental class achieved a significantly higher average of 7.26 and a median of 7.50 (see Table 1). Notably, both groups displayed non-normal score distributions as evidenced by p-values<0.05 in Shapiro-Wilk normality tests. Subsequent Mann-Whitney U tests (Table 2) yielded p-values < 0.05, leading to the rejection of the null hypothesis (H_0): equivalent learning outcomes in both groups. This statistically significant difference confirms that the experimental group's learning achievement surpassed that of the control group after the experiment.

Student Feedback on GeoGebra-Game-RME

Students who participated in the GEG-Game-RME intervention also reported that they found it to be a positive and effective learning experience. They found that the use of GeoGebra, GBL, and realistic mathematical contexts made trigonometry more interesting and understandable. Here is some feedback from students after using the GeoGebra-Game-RME model in Learning trigonometric ratios in right triangles.

S1: I think the GeG-Game-RME model is very helpful for learning trigonometric ratios. It makes the concepts more concrete and easier to understand. I especially liked the games, which were fun and challenging. I think they really helped me to solidify my understand of the material.
S2: I found the GeG-Game-RME model to be very engaging and interactive. It kept me interested in the material and made it more enjoyable to learn. I also think it was very effective in helping me to learn the concepts. I felt much more confident about trigonometric ratios now than I did before.
S3: I think the GeG-Game-RME model is a great way to learn trigonometric ratios. It is especially helpful for students who are visual learners. The models and games makes the concepts easier to understand and remember. I would definitely recommend this model to other students.

Specifically, students noted that the following aspects of the GeG-Game-RME approach were particularly helpful. First, the use of GeoGebra enabled students to visualize trigonometric concepts in ways they had never experienced before. This enhanced their understanding and allowed them to see the relationships between concepts more clearly. Second, the integration of GBL provided fun and challenging activities that kept students engaged and motivated. Third, the use of realistic mathematical contexts helped students connect trigonometry to real-world applications, making the material more relevant and interesting.

The interview results supported the findings of the pre-test and post-test. The students in the experimental group reported that they found the GeG-Game-RME approach to be more engaging and motivating than the traditional approach. They also said that they felt more confident in their ability to solve problems after using the GeG-Game-RME approach.

DISCUSSION

This study investigated the effectiveness of an integrated teaching approach of RME and GBL in teaching Trigonometry to secondary school students, seeking to understand how this blended approach impacts student learning outcomes and engagement. The findings suggest that this approach has the potential to improve student learning outcomes, particularly in problem-solving skills significantly, directly addressing the core research question of whether RME and GBL can enhance trigonometry learning. The combination of real-world contexts, central to RME, and game elements, a key component of GBL, effectively captured student interest, leading to increased engagement and a more positive learning experience. This finding is consistent with previous research on the motivational power of GBL and the importance of making learning relevant to students' lives, reinforcing the existing literature on effective pedagogical practices (Yifan et al., 2024). RME, with its emphasis on guided recreation and the use of concrete materials, facilitated a deeper understanding of mathematics concepts (Mesa et al., 2023; Van den Heuvel-Panhuizen & Drijvers, 2020). Students were able to connect abstract mathematical ideas to real-world phenomena, leading to more meaningful learning, aligning with constructivist learning theories (Yuanita et al., 2018), highlighted in the literature review. The integration of GBL provided students with opportunities to apply their knowledge in challenging and engaging ways (Hui & Mahmud, 2023; Yifan et al., 2024). Game-based activities encouraged critical thinking, strategic planning, and the development of problem-solving strategies, echoing the benefits of active learning pedagogies discussed previously (Slyman, 2024). The findings suggest that the blended approach may have contributed to more positive attitudes toward mathematics in students. This is important for fostering a lifelong love of learning and encouraging further exploration of mathematical concepts, potentially addressing the affective domain challenges often associated with mathematics learning (Slyman, 2024).

Moreover, the study explored the potential limitations and factors associated with GBL as highlighted in existing research, including the risk of over-emphasis on entertainment and potential distractions. This study acknowledges these challenges and emphasizes the crucial role of teachers in carefully selecting appropriate games and designing activities that effectively balance entertainment with educational goals. The teacher's ability to choose relevant contexts and facilitate meaningful engagement is essential for maximizing the benefits of GBL and ensuring that students remain focused on the learning objectives.

Despite the positive aspects, the study had limitations due to the small sample size and specific characteristics of the participating students. Therefore, further research with larger and more diverse samples is needed to generalize the findings and explore the impact of various game designs and implementation strategies. Future research is needed to investigate the long-term impact of this approach on student achievement and knowledge retention. Successful implementation of this approach requires adequate teacher training and support. Further research is needed to investigate effective professional development programs for teachers to integrate

RME and GBL into their teaching effectively. In conclusion, this study provides compelling evidence for the potential of integrating RME and GBL to enhance trigonometry learning. While further research is necessary to address limitations and explore long-term effects, the findings strongly support the blended approach as a promising pedagogical strategy for improving student engagement, conceptual understanding, and problem-solving skills in mathematics education.

CONCLUSION

The study demonstrated an improvement in middle school students' trigonometry understanding and problem-solving skills when using the GEG-Game-RME approach, with their average scores significantly differing from the traditional teaching methods, directly addressing RQ. This enhancement encompassed all aspects of problem-solving: understanding, planning, execution, and reflection. Notably, student engagement and confidence were also improved. The success of the approach stemmed from a synergistic combination of GeoGebra's powerful visualization capabilities with the motivating aspects of GBL. This fostered a deeper conceptual understanding of trigonometric concepts and developed crucial higher-order thinking skills essential for effective problem-solving. Based on these findings, the study advocates for the integration of technology, specifically tools like GeoGebra, and game-based elements into mainstream mathematics education. Furthermore, the research emphasizes the critical importance of connecting mathematical concepts to real-world applications to enhance student learning and motivation. Future research should explore the long-term impact of the GEG-Game-RME model and investigate its applicability across different mathematical domains.

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