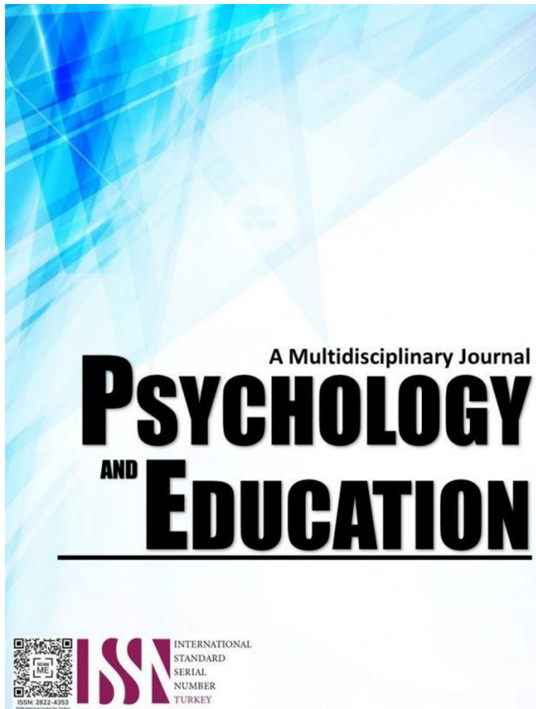
EFFECTIVENESS OF GAME-BASED LEARNING AND COLLABORATIVE PROBLEM SOLVING ON STUDENTS' MATHEMATICS PERFORMANCE



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Research Article

Effectiveness of Game-Based Learning and Collaborative Problem Solving on Students' Mathematics Performance

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Abstract

This study examined how Game-Based Learning (GBL) and Collaborative Problem-Solving (CPS) affect students' performance in mathematics, focusing on trigonometric ratios of special angles and on solving elevation and depression problems. The research took place in two government schools in Balingasag North District, Misamis Oriental, with 56 Grade 9 students. One group used game-based Learning through interactive bingo games, while the other group used collaborative problem- solving with small group sharing and teamwork exercises. The study employed a quasi-experimental design with pre- and posttests to measure impact. The data were analyzed using descriptive statistics, paired t-tests, and ANCOVA. The Results showed that both GBL and CPS helped students improve their mathematics performance, especially in engagement and excitement, problem-solving, and understanding concepts. These results suggest that GBL and CPS are promising teaching methods that can improve learning, particularly in schools with limited resources. The study offers useful information for teachers, curriculum planners, and policymakers seeking to use interactive and collaborative methods to increase math achievement, motivation, and student involvement.

Keywords: *game-based learning, collaborative problem solving, trigonometric ratio, mathematics performance, bingo game, small group sharing*

Introduction

Mathematics is a fun but challenging subject. Students often struggle with complex concepts, particularly trigonometric ratios. They frequently perceive traditional lecture-based methods as monotonous, leading to reduced engagement, lower participation, and weaker performance in mathematics.

Many students find mathematics challenging, leading to anxiety and disinterest. Traditional methods, which emphasize memorization and working alone, may not suit everyone. Math builds logical thinking, problem-solving, and analytical skills needed in life. To address these issues, teachers are adopting new methods like game-based learning (GBL) and group problem-solving (Tokac et al., 2019; Yang & Quadir, 2020).

Despite its real-life relevance, mathematics remains challenging for many high school students, leading to lower grades and reduced confidence (Clark et al., 2017). Hence, need to innovative hands-on teaching methods to improve outcomes.

Game-based learning (GBL) and collaborative problem-solving (CPS) have emerged as highly promising approaches. GBL introduces elements such as rewards and challenges into lessons, increasing student engagement and improving learning (Sailer et al., 2016b). Research highlights that GBL boosts motivation and comprehension when games target clear learning goals (Miller et al., 2020; Zhang et al., 2019). Similarly, collaborative problem-solving deepens understanding through peer communication and focused group work (Wang & Zhang, 2021).

However, most research examines GBL and CPS separately, with few studies exploring their combined impact on students' mathematical mastery (Stewart & Rieger, 2020; Sullivan & Williams, 2022). The question remains: can integrating both methods significantly enhance understanding of key mathematical concepts?

Collaboration in problem-solving enables students to discuss solutions, explore strategies, and justify reasoning, leading to a stronger grasp of mathematical principles and improved performance (Baker et al., 2015). Despite GBL and CPS's promise, questions remain about their combined effectiveness.

The study by Setyaningrum et al. (2018) found that game-based learning enhances students' interactive activities, helping them learn math more engagingly and effectively, especially in problem-solving. Atmanissa et al. (2023) showed that collaborative problem-solving improves mathematical competency, critical thinking, and classroom engagement by fostering teamwork, strategic communication, and collective problem-solving.

In the Philippines, students continue to struggle in mathematics based on national and international assessments. The PISA 2022 results show that Filipino learners remain among the lowest-performing students in the world, with no significant improvement from their 2018 performance.

According to the OECD Education GPS, Filipino 15-year-olds scored an average of 355 in mathematics, far below the OECD average of 472, and only 16% reached the minimum proficiency level required for basic mathematical problem-solving. The Inquirer also reported that the Philippines ranked sixth from the bottom in mathematics among 81 countries, highlighting persistent nationwide challenges in numeracy and critical thinking skills.

These national challenges are also reflected in rural school settings where students have limited access to technology, updated materials, and innovative teaching strategies. Being in hinterland schools, learners often experience difficulties understanding abstract mathematical concepts through traditional teaching methods, which further contributes to low performance and weak engagement in mathematics.

This study aims to directly address whether the integration of game-based learning, specifically bingo activities, with collaborative problem-solving, can meaningfully improve students' mathematical performance. It further investigated if these approaches help overcome learning challenges, particularly for students in remote areas, while fostering deeper mathematical understanding.

Research Questions

This study investigated the effects of Game-Based Learning (GBL) and Collaborative Problem-Solving (CPS) on the mathematics performance of Grade 9 students from Calawag and Quezon Integrated Schools in Misamis Oriental. Specifically, the researcher sought to respond to the following questions:

1. What is the level of Participants' performance before and after the following interventions:
   1.1 collaborative problem-solving (CPS); and
   1.2 game-based learning (GBL)?
2. Is there a significant difference in the level of Participants' Mathematics Performance before and after the Collaborative Problem-Solving intervention?
3. Is there a significant difference in the level of Participants' Mathematics Performance before and after the Game-Based Learning intervention?
4. Is there a significant difference in the level of Participants' Mathematics Performance between Collaborative Problem-Solving and Game-Based Learning interventions?

Methodology

Research Design

This study used a quantitative research method in a quasi-experimental design to control the treatment and assessment of the necessary data for the researcher. The tests before and after the two groups were analyzed to demonstrate the difference between GBL and CPS (Cresswell, 2014). These two approaches are effective ways to engage students and help them improve their understanding of Mathematics Performance

The quasi-experimental research design, specifically the pretest/posttest control-group design (Campbell & Stanley, 2015) was used in this study. This comparative design allowed comparison between two groups: one receiving the experimental intervention of collaborative problem-solving, while the other received game-based learning.

This study established the intervention's effect on the respondents' mathematics performance. The respondents were students who participated in collaborative problem-solving groups and game-based learning groups. Pre- and posttest assessments were taken from both groups to measure changes in their mathematics performance.

Respondents

This research was conducted in two government schools under the Department of Education, namely Calawag Integrated School and Quezon Integrated School, during the school year 2024–2025. The study involved purposive and convenience sampling of Grade 9 students. Purposive sampling was used to select the schools, which were non-randomized groups in a quasi-experimental approach in which respondents were often allocated into two groups. The Collaborative Problem Solving (CPS) group is composed of students from Quezon Integrated School, whereas the Game-Based Learning (GBL) group included students from Calawag Integrated School. Random assignment was not feasible, as the entire class had to be included—an approach often necessary in educational settings (Creswell, 2014).

A pilot test involved 30 students from Misamis Oriental National High School, who were not part of the main sample. The final group included 28 Grade 9 students, each from Calawag and Quezon Integrated Schools, chosen through purposive and convenience sampling. Purposive sampling was used because Calawag and Quezon Integrated Schools are rural schools with limited resources and students who struggle with mathematics. This matched the study's goal of testing how well GBL and CPS improve math performance in underserved areas. By focusing on these schools, the researcher collected data directly relevant to the study's aims and applicable to similar schools.

Convenience sampling was chosen to select students within each school because it was practical and efficient. This method allows the researcher to gather data from readily available students without random assignment. It was a good fit for the study, allowing enough students to participate within a short period. This sampling approach made sure the study's results were relevant to other rural schools with similar challenges. Both purposive and convenience sampling were used to create the two groups. The study relied on students who were willing to participate in Game-Based Learning and Collaborative Problem-Solving activities to improve math performance.

There are 28 student respondents from School A representing the Game-Based Learning group, and another 28 from School B representing the Collaborative Problem-Solving group. A total of 56 students participated in the study.

Instrument

The assessment developed for this study aimed to measure students' mathematical performance. Wellberg (2023) emphasizes the relevance of teacher-made tests in this context. These tests show how assessments impact student learning and outcomes. The analytical framework for mathematics examinations guided the creation of more effective tools to evaluate students' comprehension of mathematical concepts.

The instrument included 25 multiple-choice questions covering different cognitive processes. These ranged from basic recall of facts (Knowledge) to higher-order skills like analysis, synthesis, and evaluation. For instance, questions at the Knowledge level required students to recall basic trigonometric values. Those at the Application level asked them to solve problems using these concepts.

Research, including Perin's (2015) findings, indicates that connecting academic information to real-world contexts improves student engagement and understanding. This technique evaluates knowledge while fostering critical thinking and problem-solving, thereby enhancing the assessment's rigor and effectiveness. William (2018) asserts that examinations need to go beyond basic memorization to assess students' capacity to apply mathematical concepts in diverse circumstances, hence enhancing problem-solving skills.

The scoring system for students' performance in mathematics uses the following categories: Exceptional Mastery, Very Outstanding, Outstanding, Strong Understanding, Very Satisfactory, Good Grasp, Satisfactory, Basic Understanding, Fairly Satisfactory, Limited Comprehension, Did Not Meet Expectations, and Need for Remediation. Each category specifically reflects a range of proficiency and helps educators equitably evaluate student competencies. This methodology assesses exam scores, conceptual understanding, problem-solving skills, and mastery of mathematical topics.

This system helps teachers track progress, find gaps, and plan support. Students who need more help get extra instruction—those who do well get more challenging work. Classroom assessment shows teachers and students what is going well and what can be improved.

Procedure

Data collection began with the design of research instruments, including a validated pretest questionnaire to assess students' baseline understanding of specific mathematics concepts. After developing these instruments, the researcher submitted formal requests to the Dean of Graduate Studies at Liceo de Cagayan University and the Principals of Calawag and Quezon Integrated Schools for permission to administer pre- and posttests and to conduct school visits during the intervention phase.

After obtaining approval, the researcher recruited respondents by distributing parental consent forms through students and providing assent forms directly to students. During an orientation session, the researcher detailed the study's objectives, procedures, and ethical safeguards. Participation was voluntary, and students could withdraw at any point without repercussions. This process enabled students and guardians to make informed enrollment decisions.

After obtaining consent and assent, the researcher gave the pretest to both student groups under the same conditions, providing a baseline for measuring academic performance before the intervention. The intervention lasted about six weeks, during which the researcher visited each school twice a week. At Calawag Integrated School, Game-Based Learning strategies were used, such as bingo games and interactive activities. In contrast, at Quezon Integrated School, a teacher led Collaborative Problem Solving sessions, with students working in small groups to discuss and solve problems together.

After the intervention, the researcher gave the same test as a posttest to measure learning progress, and results from both tests were collected for analysis. To ensure strict confidentiality, names were removed, records were stored in password-protected files, and files were kept in locked cabinets accessible only to the researcher. These steps protected students' privacy and encouraged honest participation.

Data Analysis

To address the study's research questions, the following statistical tools were employed to analyze and interpret the data effectively.

For Problem 1, which examined students' performance before and after interventions, descriptive statistics were used. Measures included the mean, standard deviation, minimum, and maximum scores. These statistics gave a clear overview of central tendencies and variability within each group. They offered insights into performance trends and highlighted significant changes in students' mathematics performance from the interventions. Felix and Felix (2024) note the importance of descriptive statistics in educational research for summarizing sample characteristics and supporting sound data interpretation.

For Problems 2 and 3, determine whether the students' mathematics performance significantly changed before and after the intervention. The intervention within each group (GBL and CPS) was studied using paired t-tests. This statistical method is ideal for comparing the means of two related groups, making it particularly suitable for measuring the performance of learning interventions. To address within-subject variability, a paired t-test was used to compare the scores of the same respondents at pretest and posttest. Kanu (2024) asserts that paired t-tests are widely acknowledged in educational research for their effectiveness in evaluating the effects of interventions over time.

In Problem 4, which examined the substantial difference in posttest performance between the GBL and CPS groups after adjusting for pretest scores, Analysis of Covariance (ANCOVA) was utilized. ANCOVA is a powerful statistical method that compares one or more means while adjusting for the influence of covariates, specifically the pretest results in this instance.

This method was appropriate because it adjusted for initial differences between groups. Hence, any observed differences in posttest scores were likely due to the interventions, not pre-existing disparities. Felix and Felix (2024) support the use of ANCOVA in educational research to enhance the validity of group comparisons.

It is important to note that the assumptions underlying these statistical tests, such as normality, homogeneity of variances, and linearity, were not formally tested in this study. This limitation may affect the robustness of the statistical conclusions.

Ethical Considerations

This study strictly adhered to ethical standards to ensure the protection and welfare of all participants. Prior to data collection, formal approval was obtained from the Dean of Graduate Studies of Liceo de Cagayan University and the principals of Calawag Integrated School and Quezon Integrated School. Since the respondents were minors, informed consent was secured from parents or guardians, and assent was obtained from the students after clearly explaining the purpose, procedures, and voluntary nature of participation. Participants were informed of their right to withdraw at any time without penalty. Confidentiality and anonymity were maintained by assigning codes instead of names, and all data were securely stored in password-protected files and locked storage accessible only to the researcher.

Furthermore, the study ensured that no harm or disadvantage was imposed on the participants. Both Game-Based Learning (GBL) and Collaborative Problem-Solving (CPS) are recognized as appropriate and beneficial instructional strategies, and all activities were conducted within regular class time to avoid disruption of learning. The researcher maintained a respectful and supportive environment, free from coercion. Ethical integrity was also upheld in data analysis and reporting by ensuring accuracy, honesty, and proper citation of sources, while transparently acknowledging study limitations to preserve the credibility and trustworthiness of the research.

Results and Discussion

This section analyzes and interprets the data from the research study. The data is displayed in a tabular style. Statistical tool such as mean, standard deviation, paired sample t- test and analysis of covariance (ANCOVA) were used to examined and group differences.

What are the levels of participants' mathematics performance before and after the implementation of the interventions, Collaborative Problem-Solving Intervention (CPS), and Game-Based Learning intervention (GBL)?

Table 1. *level of students' mathematics performance in the Pretest and Posttest Intervention for CPS and GBL*

Intervention	*Pretest*			*Posttest*		
	Mean	*SD*	*Level*	*Mean*	*SD*	*Level*
Game- based-learning	8.17	2.26	Fairly Satisfactory	13.64	3.21	Very Satisfactory
Collaborative Problem- solving	7.21	2.33	Fairly Satisfactory	12.07	3.17	Satisfactory

Score Interval – Level – Interpretation: 22–25 – Very Outstanding – Exceptional Mastery; 18–21 – Outstanding – Strong Understanding; 14–17 – Very Satisfactory – Good Grasp; 10–13 – Satisfactory – Basic Understanding; 6–9 – Fairly Satisfactory – Limited Comprehension; 0–5 – Did not Meet Expectation – Need Remediation.

Table 1 presents the outcomes and their respective standard deviations for the Collaborative Problem-Solving (CPS) and Game-Based Learning (GBL) interventions. Continuing with the Game-Based Instruction, students' mean scores rose from 8.17 (SD = 2.26) to 13.64 (SD = 3.21). Meanwhile, the mean score for the Collaborative Problem-Solving intervention increased from 7.21 (SD=2.33) to 12.07 (SD=3.17). After taking part in the interventions, both sets of respondents performed better. These results support Adipat et al. (2021), who state that the intervention boosts student engagement and cognitive skills. The intervention improves problem-solving and encourages a growth mindset in decision-making throughout lifelong learning.

Both interventions improve students' academic performance and cognitive skills by emphasizing engagement, collaboration, and structured problem-solving. Yaman et al. (2025) found that these interventions increase motivation and performance when aligned with learning objectives and when teachers are prepared. Studies indicate both methods are equally effective, with no notable difference in student outcomes. Educators can choose either approach based on goals and context.

The Bingo game was used as a teaching strategy in Game-Based Learning. Each student received a bingo card with possible answers to trigonometric ratios and angle-of-elevation/angle-of-depression problems. After distributing the cards, the teacher presented problems on the board or read them aloud. Students then solved the problems and checked if their answers were on their bingo cards. If the answer was on their card, students marked it. The first to complete a line called out bingo and showed their answers for checking. The teacher verified their work. This made class more fun and interactive, encouraged participation, reduced fear of mistakes, and reinforced math concepts through engaging practice.

In the Collaborative Problem Solving (CPS) intervention, students worked in small groups of 4-5. Each group received real-world math problems using trigonometric concepts. Students discussed strategies, solved problems together, and justified their solutions with diagrams and step-by-step computations. One or more members presented the group's solution to the class. Peer learning and teacher support clarified the ambiguity of concepts and deepened their understanding on it. This strategy promoted communication, teamwork, and metacognitive skills. Students verbalized their thinking, reflected on learning, and built confidence in collaborative problem-solving.

Is there a significant difference in the level of Participants' Mathematics Performance before and after the Collaborative Problem-Solving intervention?

Table 2. *Results of the Paired-Samples T-test before and after CPS Intervention*

Test	*Mean*	*N*	*SD*	*t*	*p*	*Interpretation*
Pretest	7.21	28	2.33	-13.26	.000	Significant
Post test	12.07	28	3.17			

Table 2 shows the results of the Paired-Samples T-test to determine a significant difference in students' mathematics performance before and after the CPS interventions. The table shows that the p-value is smaller than the alpha level of .05, indicating that students' posttest (M=12.07, SD=3.17) was significantly higher compared to their pretest (M=7.21, SD=2.33).

Before the intervention, the collaborative problem- solving performed below expectations. This reflects a common issue in remote schools, where abstract mathematical concepts, such as trigonometric ratios, are difficult to master using traditional teaching methods alone. However, after the implementation of the Collaborative Problem-Solving (CPS) approach through small group sharing in Quezon, there was a notable improvement in posttest scores. Students demonstrated increased engagement and better understanding despite limited learning resources. Therefore, the null hypothesis regarding the level of students' mathematics performance before and after the Collaborative Problem-Solving intervention was rejected.

These findings are consistent with the study of Xu, Wang, and Wang (2023), who found that CPS significantly enhances students' critical thinking and problem-solving abilities by fostering active engagement and peer collaboration. Similarly, Felmer (2023) emphasized that structured collaboration enables students to articulate their reasoning and develop a shared understanding of mathematical problems, thereby improving academic performance.

Research underscores that CPS also develops essential metacognitive skills and mathematical confidence. Kim and Lim (2018) highlighted that CPS promotes metacognitive skills and mathematical confidence, which are essential for sustained learning. Their research showed that students who engaged in CPS activities were better at reflecting on their strategies and correcting errors, contributing to higher test scores.

CPS has also been shown to enhance mathematical achievement by fostering communication and analytical reasoning. García, Martínez, and Soto (2021) stated that CPS improves mathematical achievement by encouraging communication, teamwork, and analytical reasoning. These studies collectively affirm that CPS is an effective instructional strategy for enhancing students' mathematics performance.

Is there a significant difference in the level of Participants' Mathematics Performance before and after the Game-Based Learning intervention?

Table 3. *Results of the Paired-Samples T-test of participants' Mathematics Performance before and after GBL Intervention*

Test	*Mean*	*N*	*SD*	*t*	*p*	*Interpretation*
Pretest	8.17	28	2.26	-13.54	.000	Significant
Post test	13.64	28	3.21			

Table 3 presents the mean, standard deviation, and results of the paired-samples t-test for students' math performance before and after the game-based learning intervention. Since the p-value is below .05, students' posttest scores (M=13.64, SD=3.21) were significantly higher than their pretest scores (M=8.17, SD=2.26).

According to Tokac et al. (2019), their meta-analysis supports these findings, showing that game-based learning has a small but significant positive effect on students' math achievement. They also point out that even small gains matter, especially when games are designed to fit learning goals. Brezovszky et al. (2018) also found that game-based learning helps students build adaptive number knowledge and use math skills in different situations. Their research concluded that game environments help students engage with math concepts in a low-stress, high-engagement setting, which leads to better understanding and performance. The results of the present study are consistent with previous findings showing that interactive activities, such as bingo games, can enhance students' engagement and performance in mathematics.

However, the analysis revealed that students' mathematics performance did not significantly change before and after its implementation. Having established the effects of game-based learning interventions on students' math performance, the next question addresses whether there is a significant difference in mathematics performance between students exposed to the Collaborative Problem-

Solving intervention and those exposed to the Game-Based Learning intervention.

Is there a significant difference in the level of Participants' Mathematics Performance between Collaborative Problem-Solving and Game-Based Learning interventions?

Table 4 presents the results of an Analysis of Covariance (ANCOVA) for the significant difference in students' Mathematics Performance between the Collaborative Problem-Solving and Game-Based Learning interventions. As depicted in the table, the R2 value of .619 indicated that the independent variables, along with the pretest as a covariate, predicted 61.9 % of the students' Mathematics Performance. In comparison, approximately 38.1% could have been attributed to other factors not included in the study. Considering pretest learning outcomes as a covariate, students exposed to Game-Based Learning had an Estimated Marginal Mean of M=13.12. In contrast, those exposed to Collaborative Problem-Solving had an Estimated Marginal Mean of M=12.58.

Table 4. *Results of ANCOVA for the significant difference in mathematics performance between students exposed to the Collaborative Problem-Solving intervention and those exposed to the Game-Based Learning intervention*

Source	*Type III Sum of Squares*	*df*	*Mean Square*	*F*	*Sig.*	*Partial Eta Squared*
Corrected Model	361.945(a)	2	180.972	43.028	.000	.619
Intercept	93.935	1	93.935	22.334	.000	.296
Pretest	327.373	1	327.373	77.837	.000	.595
Group	3.870	1	3.870	.920	.342	.017
Error	222.912	53	4.206			
Total	9842.000	56				
Corrected Total	584.857	55				

R Squared = .619 (adjusted R Squared = .604)
Estimated Marginal Mean (GBL)=13.12
Estimated Marginal Mean (CPS)=12.58

Results of the ANCOVA indicated that the groups did not differ significantly in students' mathematical performance (F = .920, p = .342). So, it appears that there was no strong evidence to claim that students exposed to Game-Based Learning (M=13.12) performed significantly better than those exposed to Collaborative Problem-Solving (M=12.58). In terms of effect size, the partial eta squared value of .017 (p>.05) implied that the interventions used exerted a small effect on students' mathematics performance, and the effect was not significant. Thus, the null hypothesis asserts that there was no significant difference in the mathematics performance of students engaged in game-based learning versus those involved in collaborative problem-solving. Gros (2022) similarly discovered that CPS and GBL can enhance student performance, supporting these conclusions. but in different ways. Based Learning increases engagement through interactive games and quick feedback, while CPS builds social interaction and peer learning, helping students learn together. Similarly, Vass (2018) and Kim and Lim (2018) found that CPS improves critical thinking and metacognitive skills, while GBL increases motivation and engagement. Both are important for academic success. Their research suggests that how well each method works may depend more on its context and use than on the method itself.

Plass, Homer, and Kinzer (2015) stated that GBL is most effective when games match learning goals. Jonassen et al. (2016) found CPS works best when students reflect and explain their thinking. These points support this study's conclusion. Both GBL and CPS are useful, and their impact may depend on the context.

Conclusion

The findings of the study indicate that both Game-Based Learning (GBL), particularly through the use of an interactive Bingo game, and Collaborative Problem-Solving (CPS) significantly enhance students' learning experiences in mathematics. GBL increased students' motivation, engagement, and confidence, making the learning environment more interactive and enjoyable. Meanwhile, CPS strengthened students' reasoning, teamwork, and critical thinking skills by immersing them in meaningful, real-life problem contexts. These results highlight the value of active and student-centered approaches in improving both cognitive and affective learning outcomes.

Moreover, the study confirms that both instructional strategies are highly effective and can be flexibly applied depending on instructional goals and classroom contexts. While GBL is particularly effective in fostering engagement and reducing anxiety, CPS is more suited for developing higher-order thinking and collaborative skills. The effectiveness of both approaches suggests that teachers are not limited to a single method but can strategically integrate or alternate these approaches to maximize student learning and participation.

In light of these findings, it is recommended that school administrators support the integration of innovative teaching strategies by providing training and instructional resources. Teachers are encouraged to adopt GBL and CPS to create more dynamic and meaningful learning experiences, while curriculum developers should embed these approaches into instructional frameworks to promote active learning. Students, in turn, are encouraged to actively participate in such strategies to build confidence and improve retention. Future research should further explore the long-term effects of these approaches across various mathematical domains and educational levels, particularly in relation to students' attitudes, engagement, and problem-solving competencies.

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