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Android-Based Endless Runner Game Learning Media Innovations to Improve Students' Mathematical Literacy

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ABSTRACT

Purpose –This study aims to evaluate the effectiveness of Android-based endless runner games as a learning medium for improving students' mathematical literacy through interactive gameplay that integrates mathematical problem-solving with entertainment elements.

Methodology – This study employed a quasi-experimental pretest-posttest control-group design with 60 elementary students (grades 5-6), divided into an experimental (n=30) and a control (n=30) group. Data collection included a 20-item mathematical literacy test covering arithmetic, geometry, and measurement, plus feedback questionnaires measuring engagement and motivation—statistical analysis employed t-tests with normality and homogeneity of variance testing. Game quality was evaluated using the Game-based Learning Evaluation Framework.

Findings – Results demonstrated significant improvements in mathematical literacy. The experimental group achieved substantially greater gains (30.8%) than the control group (6.1%), with statistical analysis confirming significance: $t(58) = 5.67$, $p < .001$, Cohen's $d = 1.85$, representing a considerable effect. Affective outcomes were equally positive: 90% of students reported increased confidence in mathematics, 85% expressed heightened interest, and overall engagement averaged 4.2/5.0, demonstrating the intervention's effectiveness in both cognitive and motivational dimensions.

Contribution – This study contributes to validates situated learning and constructivist frameworks in mobile game contexts, demonstrating how seamless integration of learning content into gameplay mechanics enhances effectiveness. It offers educators an accessible, evidence-based mobile learning tool that simultaneously addresses achievement, engagement, and motivation—particularly valuable in resource-constrained educational settings.

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INTRODUCTION

Mathematical literacy is an essential basic competency for students' academic success and problem-solving skills in the real world. According to the 2022 Programme for International Student Assessment (PISA) released by the OECD, only about 18% of Indonesian students achieved the minimum competency level (Level 2) in mathematical literacy, well below the OECD average (around 69%). (OECD, 2022)(Sofyan et al., 2025). This deficiency goes beyond mere computational skills, encompassing students' inability to understand, interpret, and apply mathematical concepts in contextual situations. (Oliver-Barcelo et al., 2024). Contemporary research shows that approximately 71% of Indonesian elementary school students experience difficulties in mathematical reasoning and problem-solving, which is directly linked to ineffective pedagogical approaches (Lubis et al., 2025). Traditional mathematics learning, which is dominated by lecture and memorization methods, fails to engage digital-generation learners accustomed to technology-based, interactive experiences (Khasawneh et al., 2023).

The proliferation of mobile technology, particularly smartphones and tablets, presents tremendous opportunities for educational innovation. Research shows that 78% of elementary school students in Indonesia have regular access to mobile devices, creating a foundation for technology-integrated learning interventions. (Nugroho et al., 2023). Game-based learning has emerged as a promising pedagogical approach that leverages game mechanics to enhance engagement, motivation, and knowledge retention. (Amalia et al., 2025). The endless runner game genre, characterized by continuous movement, obstacle navigation, and progressive difficulty, offers unique affordances for educational adaptation due to its intuitive mechanics and potential for sustained engagement. (Jovan et al., 2023). Existing educational games often lack rigorous pedagogical design or fail to align closely with curriculum standards, limiting their educational effectiveness. (Aaltonen & Elina, 2022).

The development of game-based learning potential has several critical gaps that remain in current research and practice. First, there is limited empirical evidence on the effectiveness of explicitly designed endless runner games for mathematics literacy development in the context of basic education (Harahap et al., 2025). While various studies have explored educational games in general(Gallego-durán et al., 2019), few have systematically investigated how the unique mechanics of endless runner games can be purposefully designed to target specific mathematical competencies. Second, most existing educational games prioritize engagement over learning outcomes, failing to demonstrate significant improvements in measurable academic performance (Zuhri et al., 2025). Third, the Indonesian educational context presents unique challenges, including limited infrastructure, a diverse student population, and specific curriculum requirements that generic educational games fail to adequately address (Usman Jayadi & Arman Harahap, 2023).

Mathematics education in Indonesian elementary schools currently faces several interrelated challenges. Students often report mathematics as their least favorite subject, citing its difficulty, abstract nature, and lack of relevance to their lives(Buyung,Rika Wahyuni, 2022). Teachers, constrained by large class sizes and limited resources, struggle to provide individual attention or use innovative teaching methods. (Agustina, Winarti, 2024). The gap between students' digital fluency in recreational contexts and their limited exposure to educational technology creates missed opportunities for pedagogical innovation. (Rahmaniar et al., 2025). Collectively, these challenges contribute to persistently low levels of mathematical literacy, perpetuating a cycle of disengagement and low achievement that extends into secondary education and beyond.

This study evaluates the effectiveness of an Android-based endless runner game designed to improve elementary school students' mathematical literacy. The game integrates mathematical problem-solving directly into the gameplay mechanics, requiring players to solve arithmetic, geometry, and measurement problems to advance through increasingly challenging levels. Unlike conventional educational games that merely layer mathematical content onto the game structure, this game embeds mathematical reasoning as an integral component of the core gameplay, ensuring that learning and entertainment are closely intertwined (Indrasvari et al., 2021). The novelty of this research is manifested in several key dimensions. First, it is one of the first systematic attempts to leverage the mechanics of endless runner games specifically for the development of mathematical literacy, offering insights into how the genre's affordances can be optimized for educational purposes. Second, the game was designed with careful attention to Indonesian curriculum standards and cultural context, ensuring its relevance and applicability in the target educational setting. Third, the study employs a rigorous quasi-experimental design with an adequate sample size and validated instruments, thereby overcoming the methodological limitations common to previous game-based learning studies. Fourth, the game is optimized for low-spec devices and offline functionality, directly addressing infrastructure constraints typical in Indonesian schools and expanding accessibility for underserved student populations. This study aims to answer the following research questions: (1) Does the Android-based endless runner game significantly improve students' mathematical literacy compared to traditional learning? (2) How do students perceive the effectiveness of games in improving their understanding of mathematical concepts? (3) What specific game features contribute most effectively to learning outcomes? By answering these questions, this study contributes both theoretically to the science of game-based learning and practically to educational innovation in the Indonesian context. The findings are expected to inform the design of future educational games, curriculum development, and technology integration strategies, ultimately improving mathematics literacy outcomes for elementary school students.

METHODOLOGY

Research Design

This study used a quasi-experimental design with a pretest-posttest control group to evaluate the effectiveness of Android-based endless runner games in improving elementary school students' mathematical literacy. The quasi-experimental design was chosen as the most appropriate approach based on several methodological and practical considerations. First, this design allows researchers to assign participants to experimental and control groups without requiring complete randomization, which is highly relevant given that students are already organized into existing class structures.(Engeness, 2025). Second, randomly assigning individual students to experimental and control groups is not feasible in a school setting because it can disrupt the regular learning process and established class structure (Khatoon & Jones, 2022). The experimental group received mathematics instruction using endless runner games as the primary medium, while the control group followed traditional mathematics instruction in accordance with the standard curriculum. Both groups were assessed using identical instruments at the beginning and end of the study. Assessments were conducted before and after the four-week intervention period to measure changes in students' mathematical literacy. The research framework illustrating the overall research design is presented in Figure 1.

As shown in Figure 1, the study began by dividing participants into two groups based on existing classes. Both groups then underwent a pretest to measure their initial level of mathematical literacy. During the four-week intervention period, the experimental group used endless runner games in mathematics learning, while the control group followed traditional teaching methods. After the intervention, both groups underwent a posttest using the same instrument as the pretest to assess changes in mathematical literacy. The data obtained was then analyzed using inferential statistics to determine the effectiveness of game-based interventions.

Participants

The research sample consisted of 60 students enrolled in grades 5 and 6 of elementary school, aged between 10 and 12 years. Participants were divided into two groups: an experimental group (n=30) and a control group (n=30). Sampling used purposive sampling based on existing class assignments to maintain ecological validity and minimize disruption to the regular academic schedule.

Learning Media

This study uses an Android-based endless runner game developed explicitly for mathematics learning at the elementary school level. The game is designed to seamlessly integrate mathematical problem-solving into gameplay mechanics, where students must solve math problems as the character moves forward, avoiding obstacles.

Technical Specifications

The game runs on Android 5.0 or later and requires 2GB of RAM, making it compatible with most smartphones available in Indonesia. The offline feature allows the game to operate entirely without an internet connection after initial installation, overcoming the common connectivity limitations in school environments.

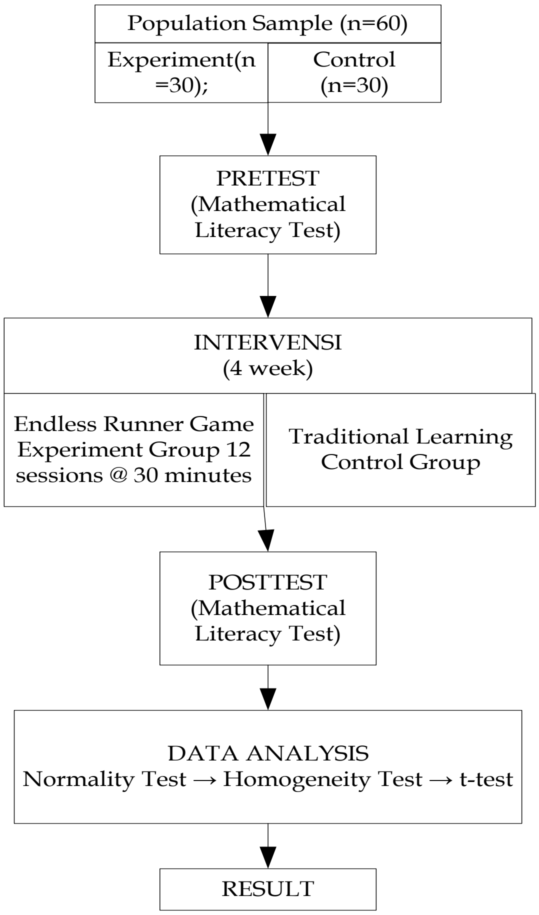


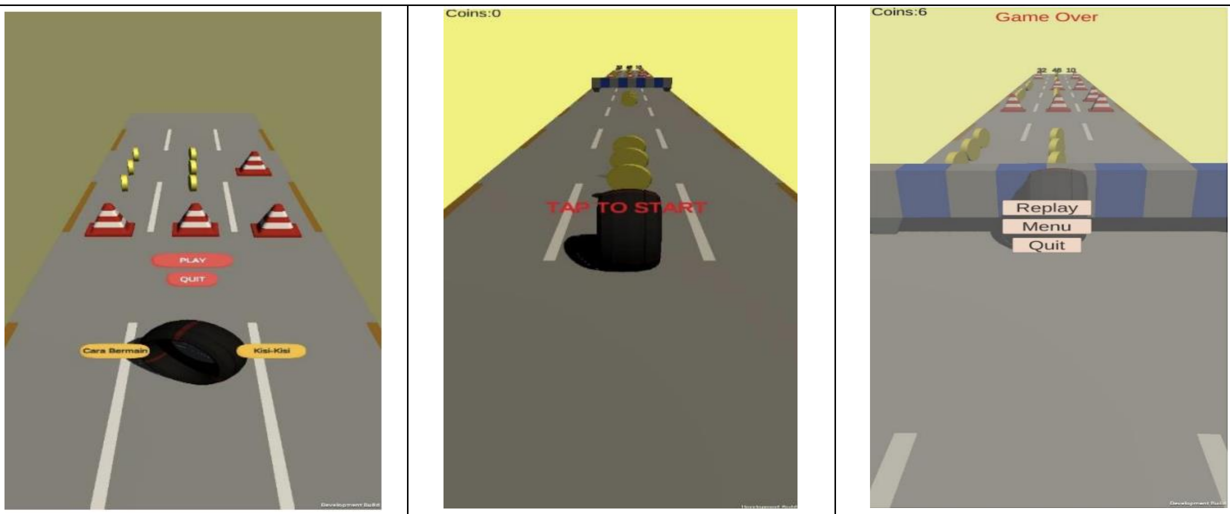
Figure 1. Research Framework

Key Features

This game includes several key features designed to support learning while maintaining engagement: (1) Progressive Difficulty System: math problems increase in complexity as players advance through levels, providing a tiered learning experience consistent with proximal development zone theory; (2) Instant Feedback Mechanism: players receive immediate visual and auditory feedback on the correctness of their answers, facilitating quick error correction and reinforcing the learning of correct concepts; (3) Diverse Content Domains: each gameplay session randomly integrates questions from the domains of arithmetic, geometry, and measurement, ensuring comprehensive coverage of mathematical content; (4) Performance Tracking: the game records completion rates, accuracy, and completion times for further analysis.

User Interface and Experience

This game features a streamlined interface designed to minimize cognitive load while maximizing focus on mathematical problem-solving. The main menu screen provides clear navigation options to start the game, view high scores, and access settings.



Main Menu Display	Game Menu Display	Game Over Menu Display

Figure 2. The Display of Features Game

During active gameplay, the screen is divided into three functional zones: (1) the game world displaying characters, obstacles, and background; (2) the math problem area displaying the current question; and (3) answer choices that players can select. The character automatically runs forward continuously, requiring players to time their jumps to avoid obstacles while simultaneously solving math problems. This design creates mild time pressure that encourages quick decision-making and mathematical fluency without causing excessive anxiety. When the gameplay session ends (either by colliding with an obstacle or by completing a level segment), the game-over screen displays a summary of performance, including score, accuracy, and the level achieved. This interface provides clear performance feedback while encouraging players to try again and improve their results.

Instruments

Two main instruments were used to collect data in this study: a mathematics literacy test and a student perception questionnaire.

Mathematical Literacy Test

The achievement test consists of 20 multiple-choice items designed to assess students' competence in three domains of mathematics: (1) Basic Arithmetic: addition, subtraction, multiplication, and division with integers and decimals (8 items); (2) Geometry and Spatial Reasoning: shape identification, area and perimeter calculations, understanding of symmetry concepts (6 items); (3) Measurement and Practical Applications: unit conversion, real-world problem solving involving time, money, and length (6 items). Each item is scored 0 for an incorrect answer and 5 for a correct answer, resulting in a maximum total score of 100 points. The instrument has been validated through expert judgment and pilot testing with a Cronbach's alpha reliability coefficient of 0.84.

Student Perception Questionnaire

The perception questionnaire consists of 15 items using a 5-point Likert scale (1=strongly disagree to agree 5=strongly) to assess students' perceptions of game-based learning experiences. The items are grouped into three dimensions: (1) Engagement Dimension: measures the extent to which games make learning enjoyable and engage students' active attention (5 items); (2) Motivation Dimension: assesses the impact of games on students' motivation to learn mathematics and their self-confidence (5 items); (3) Learning Effectiveness Dimension: evaluates students' perceptions of how games help their understanding of mathematical concepts (5 items). This questionnaire has been validated with a Cronbach's alpha reliability coefficient of 0.87.

Data Collection Procedure

Data collection took place over four main phases during five weeks. (1) Pretest, before the intervention began, all participants (experimental and control groups) completed a standardized math literacy test under controlled testing conditions. The test was administered in a single 60-minute session in their respective classrooms. (2) Intervention, the experimental group engaged in regular gameplay sessions with endless runner games for four weeks. Students played the games for 30 minutes per session, three times a week (12 sessions in total), under the supervision of their classroom teachers. Meanwhile, the control group received traditional math instruction following the standard curriculum, including teacher lectures, textbook exercises, and written assignments of equivalent duration and frequency. (3) Posttest, after completing the four-week intervention period, all participants completed a posttest identical in structure and difficulty to the pretest. The posttest was administered under the same conditions as the pretest to ensure measurement consistency. (5) Perception Questionnaire, students in the experimental group completed a structured perception questionnaire to assess their experience with game-based learning. The questionnaire was administered after the posttest.

Data Analysis

Data analysis was conducted in several stages to answer the research questions. For the math literacy test data, descriptive statistics were first calculated for the pretest and posttest scores of both groups, including the Mean, standard deviation, and gain score (the difference between the posttest and pretest). Before performing inferential statistical tests, the assumptions of normality and homogeneity of variance were assessed using the Shapiro-Wilk and Levene tests, respectively. Once the assumptions were met, an independent-samples t-test was performed to compare gain scores between the experimental and control groups to determine whether there was a statistically significant difference at $\alpha=0.05$. The effect size was calculated using Cohen's d to assess the magnitude of the difference. For the perception questionnaire data, descriptive statistics (mean and standard deviation) were calculated for each item and the overall perception score. The average scores were categorized as follows: 1.00-1.80 = Strongly Disagree; 1.81-2.60 = Disagree; 2.61-3.40 = Neutral; 3.41-4.20 = Agree; 4.21-5.00 = Strongly Agree. Pearson's correlation analysis was conducted to explore the relationship between specific game features and learning outcomes.

FINDINGS

This study produced three main findings related to the effectiveness of Android-based endless runner games for elementary school students' mathematics learning. The findings are presented in sequence according to the formulated research questions: improvement in mathematical literacy, students' perceptions of the effectiveness of games, and the game features that contribute most to learning outcomes.

RQ1: Improvement in Mathematical Literacy

Before conducting the primary analysis, assumption tests were performed to ensure the validity of the parametric statistical procedures. The Shapiro-Wilk test confirmed normality of the distribution for both groups (experimental: $W = 0.96$, $p = 0.28$; control: $W = 0.94$, $p = 0.19$), while Levene's test indicated homogeneity of variance ($F = 1.42$, $p = 0.24$). These results justified the use of independent-samples t-tests to compare group means. Table 1 presents the descriptive statistics and the results of the independent-samples t-test comparing mathematical literacy scores between the experimental and control groups.

The experimental group showed a substantial increase from the pretest ($M = 65.0$, $SD = 12.4$) to the posttest ($M = 85.0$, $SD = 8.3$), resulting in an average gain score of 20.0 points, representing a 30.8% improvement. In contrast, the control group showed minimal improvement from the pretest ($M = 66.0$, $SD = 12.8$) to the posttest ($M = 70.0$, $SD = 10.2$), with an average gain score of only 4.0 points, or 6.1% improvement. The independent samples t-test revealed a statistically significant difference in gain scores between groups, $t(58) = 5.67$, $p < .001$. These findings indicate that students who used the Android-based endless runner game experienced significantly greater improvement in mathematical literacy compared to those who received traditional instruction. The effect size, calculated as Cohen's d, was 1.85, indicating a huge effect according to standard conventions (Farid Anvari, 2021), which represents a substantial practical difference in learning outcomes.

Table 1. Descriptive Statistics and Independent Samples t-test Results

Group	n	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD	Gain Mean	t	p
Experiment	30	65.0	12.4	85.0	8.3	20.0	5.67	< 0.001**
Control	30	66.0	12.8	70.0	10.2	4.0		

Note: Maximum score = 100. Mean = average; SD = standard deviation; Gain Mean = average difference between posttest and pretest scores. **p < 0.001 (two-tailed). Cohen's d = 1.85 (experimental group), indicating a huge effect size.

Student performance was further analyzed across three mathematical content domains: arithmetic, geometry, and measurement. Table 2 presents the percentage improvements and statistical analyses for each domain.

Table 2. Performance Improvement Based on the Mathematics Domain

Mathematics Domain	Experimental class upgrade (%)	Class upgrade Control (%)	t-value	p-value
Arithmetic	22.3	4.5	4.82	< 0.001
Geometry	19.1	3.8	5.45	< 0.001
Measurement	18.5	3.2	5.78	< 0.001

Note: Improvement is calculated as the percentage gain score from the pretest to the posttest. All differences are significant at the p < 0.001 level.

Analysis of performance across mathematical domains revealed significant improvements in all three areas. The arithmetic domain showed the most significant improvement in the experimental group (22.3% compared to 4.5% in the control group, $t(58) = 4.82$, $p < .001$), followed by geometry (19.1% vs. 3.8%, $t(58) = 5.45$, $p < .001$) and measurement (18.5% vs. 3.2%, $t(58) = 5.78$, $p < .001$). All differences were statistically significant ($p < .001$), indicating that the game-based intervention was effective across the full range of mathematical content taught. The relatively consistent improvement across domains (ranging from 18.5% to 22.3%) indicates that the game's design effectively addressed multiple facets of mathematical literacy rather than focusing solely on computational skills.

RQ2: Student Perceptions and Engagement

The second research question examined how students perceived the game's effectiveness in improving their understanding of mathematical concepts. Table 3 presents students' perceptions across three dimensions: engagement, motivation, and learning effectiveness.

Student perceptions of the game were overwhelmingly positive, with an overall average score of 4.2 out of 5.0, indicating strong agreement that the game was effective for learning mathematics. Across the engagement dimension, 85% of students agreed that the game made learning mathematics more interesting (M = 4.3, SD = 0.6), while 83% reported being actively engaged while playing (M = 4.2, SD = 0.7). These findings suggest that the game successfully captured and maintained student attention, addressing a common challenge in traditional mathematics instruction.

In the motivation dimension, 90% of students reported feeling more confident in solving math problems after using the game (M = 4.5, SD = 0.5), while 78% indicated that the game increased their motivation to learn mathematics (M = 4.1, SD = 0.8). The exceptionally high confidence scores suggest that the game's design—

featuring progressive difficulty levels and immediate feedback—helped students develop self-efficacy in mathematical problem-solving.

Table 3. Students' Perceptions of Game-Based Learning Experiences (n = 30)

Perception Item	Average Score	Category
Dimensions of Engagement		
Games make learning mathematics more interesting	4.3	Strongly Agree
I am actively involved when playing games.	4.2	Strongly Agree
Dimensions of Motivation		
Games increase my motivation to learn mathematics.	4.1	Agree
I feel more confident solving math problems.	4.5	Strongly Agree
Dimensions of Learning Effectiveness		
Games help me better understand mathematical concepts.	4.3	Strongly Agree
I prefer game-based learning to traditional methods.	4.1	Agree
Overall Perception Score	4.2	Strongly Agree

Note: The average score was calculated from a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree) completed by 30 students per item. Categories are determined based on the following ranges: 1.00-1.80 = Strongly Disagree; 1.81-2.60 = Disagree; 2.61-3.40 = Neutral; 3.41-4.20 = Agree; 4.21-5.00 = Strongly Agree.

Regarding learning effectiveness, 87% of students agreed that the game helped them better understand mathematical concepts ($M = 4.3$, $SD = 0.6$), and 78% preferred game-based learning over traditional methods ($M = 4.1$, $SD = 0.7$). These perceptions align with the objective learning outcomes demonstrated in the achievement data, indicating consistency between students' subjective experiences and actual performance improvements.

RQ3: Effective Game Features

The third research question identified specific game features that most effectively contributed to learning outcomes. Correlation analysis was conducted to examine relationships between students' ratings of various game features and their improvement in mathematical literacy.

Three game features demonstrated robust correlations with learning outcomes. Immediate feedback mechanisms showed the highest correlation with improvements in mathematical literacy ($r = 0.68$, $p < .001$), indicating that students who valued instant feedback on their answers showed greater learning gains. The progressive difficulty system also demonstrated a strong positive correlation ($r = 0.61$, $p < .001$), suggesting that adaptive challenge levels effectively maintained students in their zone of proximal development. Content diversity across mathematical domains showed a moderate positive correlation ($r = 0.54$, $p < .001$), indicating that exposure to varied mathematical concepts within the game context contributed to broader literacy development.

These findings highlight that learning effectiveness in game-based environments depends not merely on the presence of game elements but on thoughtful pedagogical design. The features that proved most effective—immediate feedback, progressive difficulty, and content diversity—all serve specific learning functions: supporting formative assessment, maintaining appropriate challenge levels, and promoting transfer across mathematical domains. This suggests that educational game developers should prioritize pedagogically-grounded features over purely entertainment-focused elements when designing learning interventions.

DISCUSSION

This study investigated the effectiveness of an Android-based endless runner game in improving elementary students' mathematical literacy. The findings provide robust evidence that game-based learning can significantly enhance mathematical achievement, engagement, and motivation among elementary students. This section interprets the key findings in relation to existing literature, explores theoretical and practical implications, acknowledges limitations, and suggests directions for future research.

Summary and Interpretation of Findings

This study aimed to evaluate the effectiveness of an Android-based endless runner game in improving elementary students' mathematical literacy. The findings yielded three key insights aligned with the research questions.

Regarding the first research question on the game's effectiveness in improving mathematical literacy, results showed that the experimental group achieved a 30.8% improvement, compared with 6.1% in the control group, with a considerable effect size (Cohen's d = 1.85). This substantial improvement can be attributed to several learning mechanisms. First, the seamless integration of mathematical problem-solving into core gameplay mechanics created an authentic learning context where students had to apply mathematical concepts to achieve game objectives. Unlike traditional worksheets, where mathematics exists as an isolated academic exercise, the game embedded mathematical reasoning within meaningful goal-oriented activities, aligning with situated learning theory (Arlianti et al., 2025), which emphasizes that knowledge is most effectively acquired when learned in contexts similar to those in which it will be applied.

Second, the immediate feedback system allowed students to instantly recognize correct or incorrect answers and make corrections, facilitating learning through trial and error. This aligns with the formative assessment principles articulated by(Tambunan et al., 2022), which state that continuous feedback supports learning by helping students identify gaps in their understanding and adjust their strategies accordingly. The game environment provided a psychologically safe space for making mistakes—errors resulted in game obstacles rather than social embarrassment or grade penalties, reducing mathematics anxiety that often inhibits student experimentation and risk-taking in traditional classroom settings (Maulana et al., 2022).

Third, the progressive difficulty system ensured students were continuously challenged at appropriate levels, consistent with Vygotsky's concept of the zone of proximal development (Fani & Ghaemi, 2011). As students demonstrated mastery at one level, the game automatically increased complexity, maintaining optimal challenge that was neither frustratingly difficult nor boringly simple (Harahap & Hasibuan, 2025). This adaptive scaffolding supported differentiated instruction without requiring teacher intervention, addressing the practical challenge of meeting diverse student needs in typical classroom contexts.

The domain-specific analysis revealed substantial, statistically significant improvements across all three mathematical content areas—arithmetic (22.3%), geometry (19.1%), and measurement (18.5%)—with relatively consistent gains. This pattern suggests that the intervention's effectiveness extended beyond procedural computational skills to spatial reasoning and practical application domains. The slightly greater improvement in arithmetic may reflect the greater frequency of arithmetic problems within the game design, or it may indicate that arithmetic concepts are more amenable to the fast-paced endless runner format. Nonetheless, the consistent improvement across domains demonstrates the intervention's comprehensive impact on mathematical literacy.

For the second research question regarding student perceptions, findings revealed that 90% of students reported increased confidence, 85% expressed heightened interest in mathematics, and the average perception score reached 4.2/5.0, indicating strong agreement with the game's effectiveness. These positive perceptions are particularly noteworthy given that Indonesian students often exhibit mathematics anxiety and negative attitudes toward the subject (Buyung,Rika Wahyuni, 2022). The game successfully transformed what many students perceive as a tedious academic obligation into an engaging recreational activity, addressing motivational barriers that traditional instruction often fails to overcome.

The high confidence scores (M = 4.5/5.0) are especially significant. Self-efficacy—students' beliefs about their capability to succeed—is a strong predictor of academic achievement (Meng & Zhang, 2023). The game's design features supported self-efficacy development through several mechanisms: achievable challenges at each level provided success experiences; visual progress indicators (points, levels, achievements) offered explicit recognition of competence; and the narrative framing of mathematical problem-solving as "game challenges" rather than "academic tests" reduced evaluative threat. These affective outcomes are as important as the cognitive gains, as positive attitudes and confidence are likely to sustain mathematics engagement beyond the study period.

Concerning the third research question about practical game features, correlation analysis revealed that immediate feedback mechanisms ($r = 0.68$, $p < .001$), progressive difficulty systems ($r = 0.61$, $p < .001$), and content diversity ($r = 0.54$, $p < .001$) showed the strongest relationships with learning improvement. These findings underscore that learning effectiveness in game-based environments depends not merely on entertainment value but on pedagogically sound design. The features that proved most effective all serve specific learning functions: immediate feedback enables continuous formative assessment, progressive difficulty maintains appropriate challenge levels, and content diversity promotes transfer across mathematical domains.

Comparison with Previous Research

The findings of this study are consistent with previous studies demonstrating the effectiveness of game-based learning in mathematics (Zuhri et al., 2025). They found that design thinking-based educational games improve students' mathematical thinking skills, in line with our findings on improved mathematical literacy. Similarly, Sofyan et al. (2025) show that a contextual learning approach can improve students' mathematical literacy, underscoring the importance of contextualizing mathematical content in meaningful application scenarios, which is also applied in our game through the integration of questions into the gameplay context.

This study shows a larger effect size than that reported in several similar studies. This difference may be due to several factors: (1) the endless runner format provides continuous engagement with a balance between gameplay challenges and mathematical learning that may be more effective than other game genres; (2) the game is specifically designed for the Indonesian context, taking into account local infrastructure constraints such as offline capabilities and low device requirements, making it more accessible; (3) the four-week intervention duration (12 sessions totaling 360 minutes) may provide sufficient exposure to demonstrate substantial learning effects while avoiding fatigue; (4) the use of existing classes (quasi-experimental design) reflects real implementation conditions in schools.

Research Implications

The findings of this study have several important implications for educational practice and policy. First, the results show that mobile technology can be used effectively to improve mathematics learning, even in contexts with limited infrastructure. The games' offline capabilities and low device requirements make them accessible to schools that may not have reliable internet connectivity or sophisticated devices, helping overcome the digital divide that often hinders the implementation of educational technology in Indonesia. Second, the intervention's substantial motivational impact shows that game-based learning can overcome math anxiety and improve students' attitudes toward mathematics—factors critical to long-term math success. A total of 90% of students reported increased confidence, and 85% expressed increased interest in mathematics. These findings suggest that games not only improve academic achievement but also the affective dimension of mathematics learning, which is often overlooked in traditional approaches. Third, identifying specific practical game features (progressive level systems, immediate feedback, endless runner format) provides concrete guidance for developers and educators who want to create or adapt educational games for other subjects. These design principles can be replicated across various content domains.

Research Limitations

This study has several limitations that must be acknowledged. First, the relatively small sample size (60 students from one school) limits the generalization of findings to a broader population. Future research should conduct multi-school studies with larger samples across diverse geographical and socioeconomic contexts. Replication across a more diverse student population will more comprehensively validate the game's effectiveness. Second, the short duration of the intervention (four weeks) did not allow for the evaluation of long-term learning effects or knowledge retention. Follow-up research is needed to assess whether the observed improvements in mathematical literacy are sustained over time and whether learning transfers to other mathematical contexts. Third, quasi-experimental designs, while practical for school settings, are not as robust as randomized controlled trials in establishing causality. Non-random assignment to the experimental and control groups means that pre-existing differences between groups cannot be completely ruled out as alternative explanations for the results, although similar pretest scores mitigate this concern. Fourth, this study measured mathematical literacy only through written tests and student perceptions only through self-report questionnaires. Future research could use additional data collection methods, such as more in-depth gameplay log analysis, physiological measures of engagement, or assessment of mathematical performance in real-world contexts, to provide a more comprehensive understanding of the impact of learning.

CONCLUSION

This study shows that Android-based endless runner games are a practical way to improve elementary school students' mathematical literacy. A statistically significant improvement in mathematics achievement (30.8% vs. 6.1%), combined with highly positive student perceptions (average score of 4.2/5.0) and strong engagement, provides strong empirical evidence for the potential of game-based learning in mathematics education. Successful implementation in authentic classroom settings demonstrates the practicality and scalability of this approach. Games can be integrated into existing classroom routines without excessive disruption, with offline capabilities and low device requirements that overcome typical infrastructure constraints in Indonesian schools. This research offers promising opportunities for educational innovation and demonstrates that familiar game formats can be adapted for rigorous educational purposes while maintaining student engagement and motivation. As mobile technology use in Indonesian schools becomes more widespread, game-based learning approaches offer a promising avenue to improve mathematics education outcomes and address the achievement gap highlighted by international assessments such as PISA.

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