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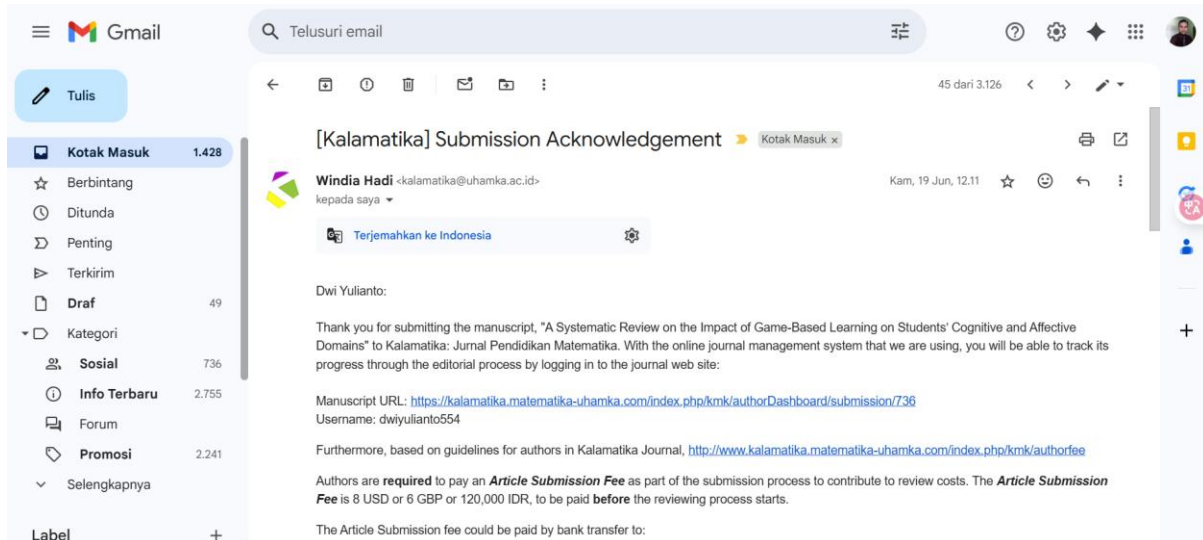
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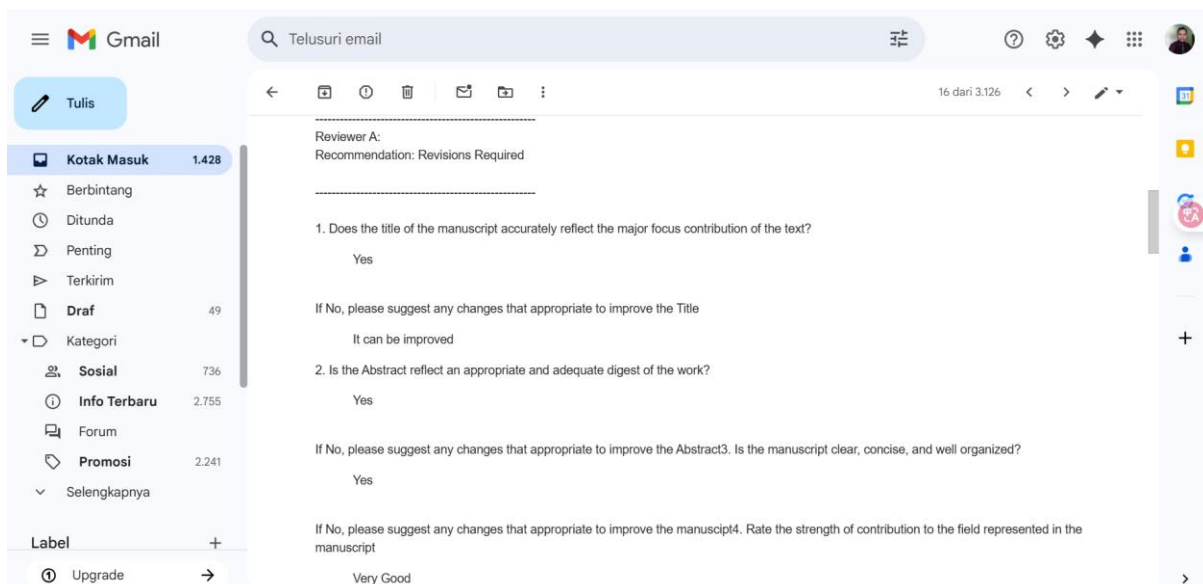
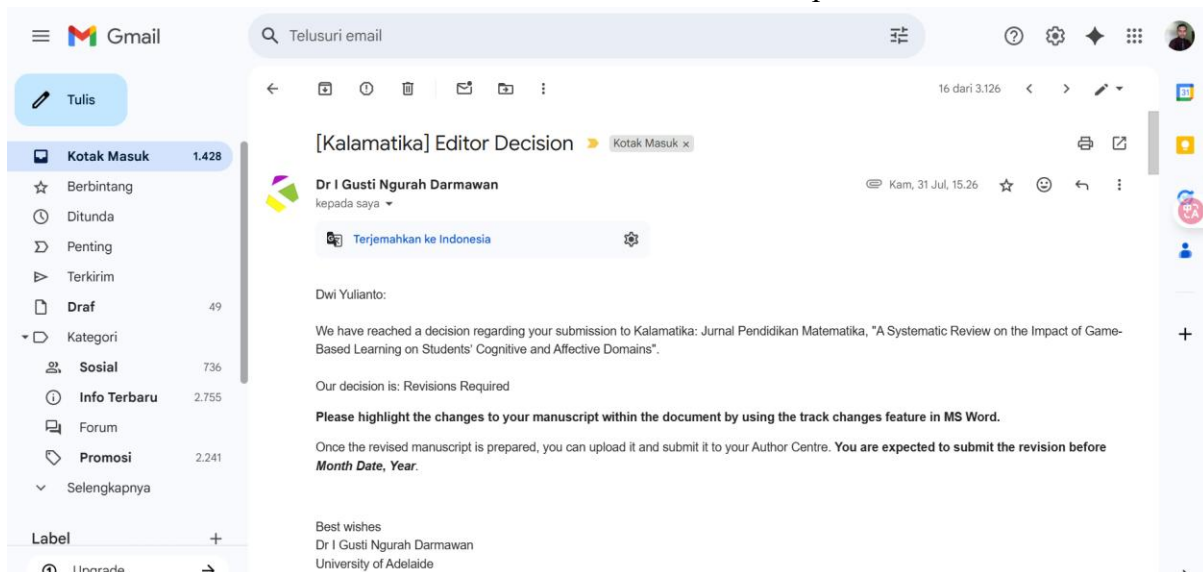
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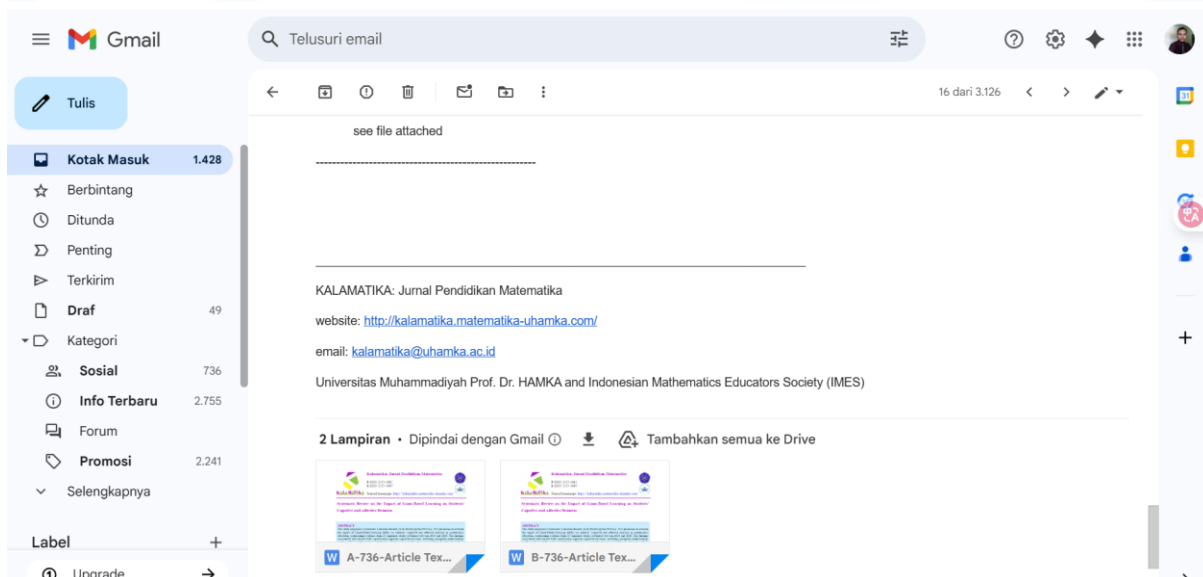
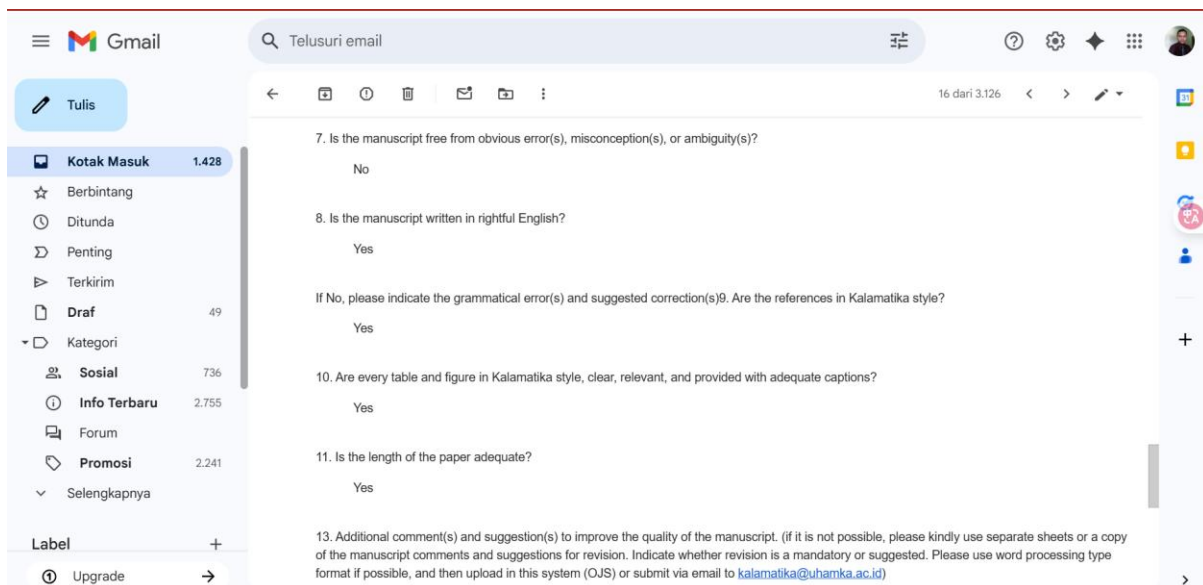
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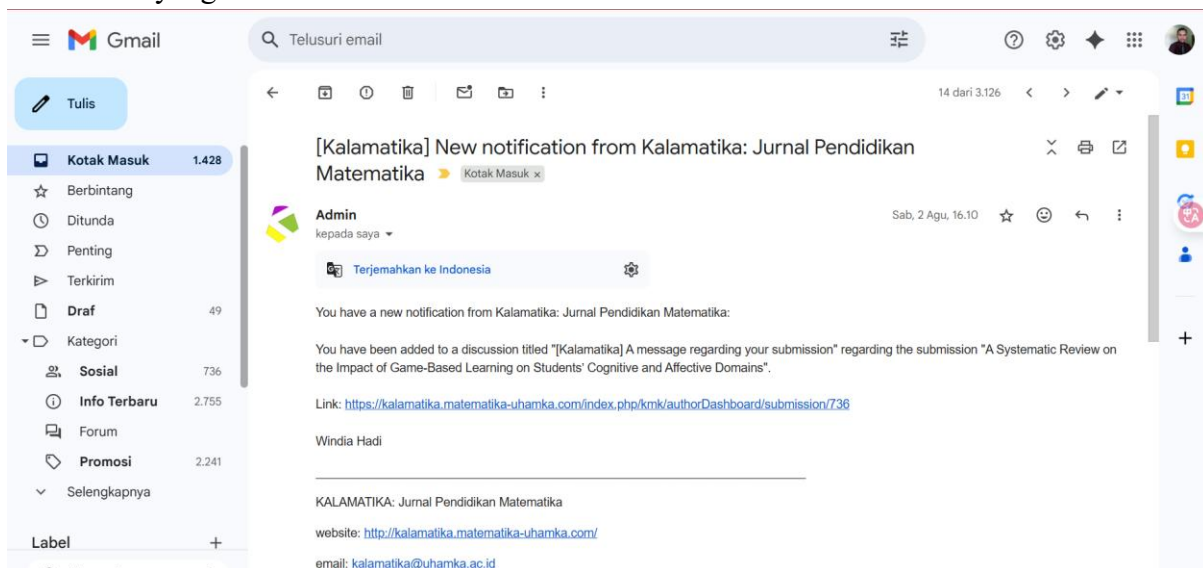
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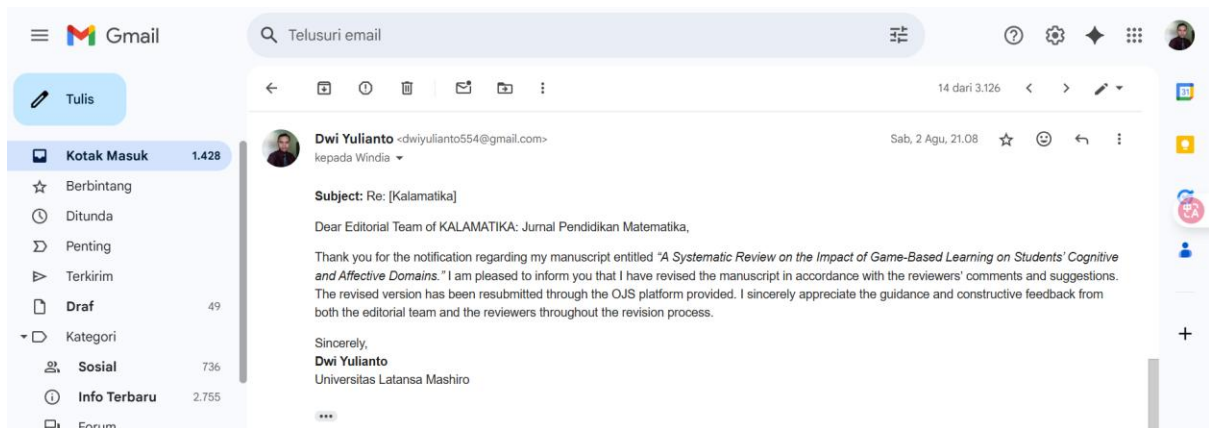
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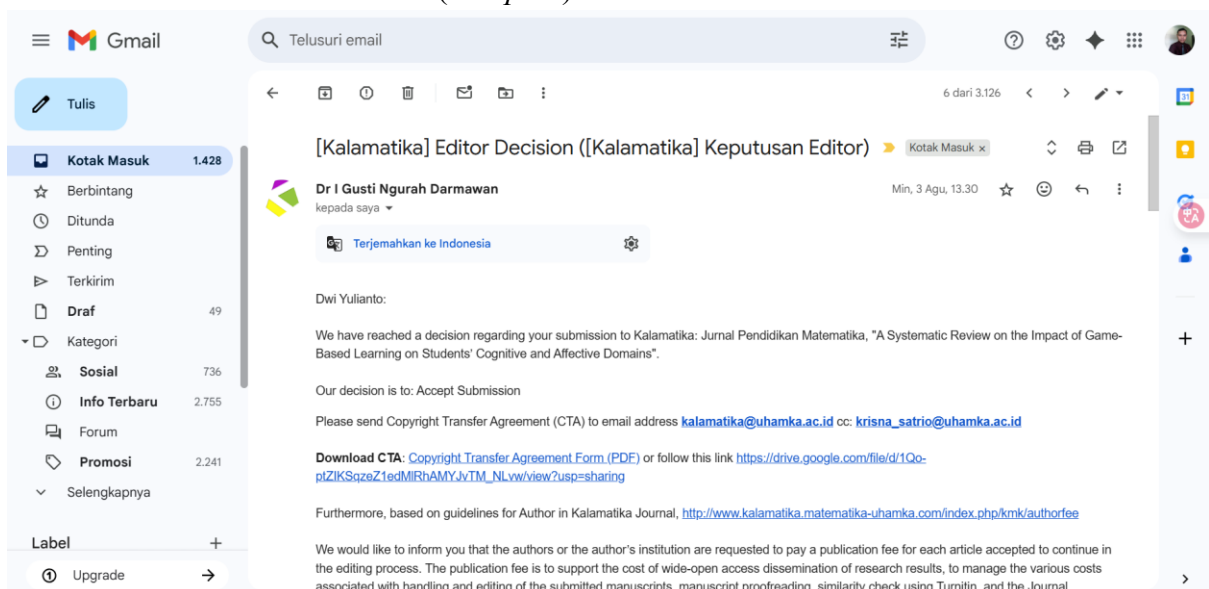


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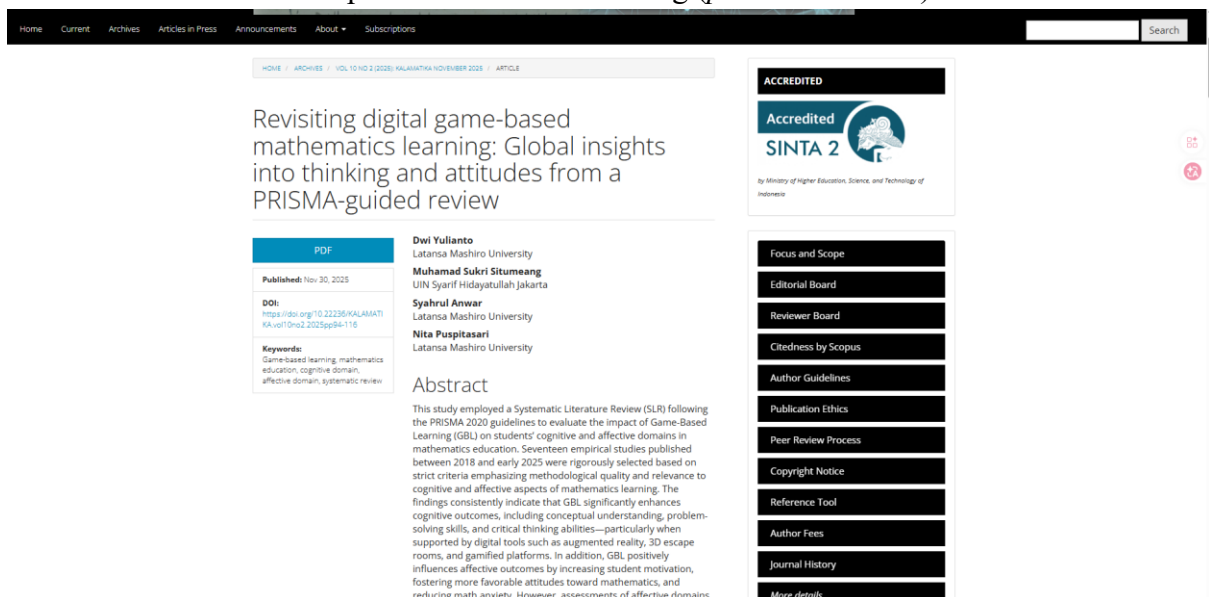




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Systematic Review on the Impact of Game-Based Learning on Students' Cognitive and Affective Domains

ABSTRACT

This study employed a Systematic Literature Review (SLR) following the PRISMA 2020 guidelines to evaluate the impact of Game-Based Learning (GBL) on students' cognitive and affective domains in mathematics education, synthesizing evidence from 17 empirical studies published between 2018 and 2025. The findings consistently indicate that GBL significantly improves cognitive outcomes, including conceptual understanding, problem-solving skills, and critical thinking abilities, particularly when supported by digital tools such as augmented reality, 3D escape rooms, and gamified platforms. In addition, GBL positively influences affective outcomes by increasing student motivation and fostering more favorable attitudes toward mathematics, while also reducing math anxiety. However, assessments of affective domains remain less standardized compared to those of cognitive outcomes. Key contextual factors such as students' prior knowledge, the quality of game design, intervention duration, and teacher preparedness were found to be critical in determining GBL effectiveness. The review highlights the dominance of digital GBL in resource-rich environments, while also recognizing the potential of non-digital adaptations in low-resource contexts. Drawing on diverse international evidence, this review underscores GBL's potential as an innovative pedagogical strategy that effectively integrates cognitive and affective learning. Practical recommendations include culturally responsive game design, comprehensive teacher training, and equitable access to technology to ensure successful GBL implementation across varied educational settings.

KEYWORDS

Game-Based Learning; Mathematics Education; Cognitive Domain; Affective Domain; Systematic Review

INTRODUCTION

Mathematics education, both in developed and developing countries like Indonesia, is fundamental in preparing learners for the demands of the 21st century marked by digitalization, automation, and complex problem-solving (Szabo et al., 2020; Yulianto et al., 2024). However, despite its importance, mathematics often triggers anxiety and disengagement, leading to low achievement worldwide, especially in developing regions where PISA and TIMSS scores remain below the OECD average (PISA 2022 Results (Volume I), 2023). These challenges call for pedagogical innovation beyond curriculum reform, emphasizing cognitive and affective integration. Effective learning requires student-centered strategies that build reasoning, conceptual fluency, and motivation. In response, Game-Based

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1. Synthesizing Evidence on Game-Based Learning in Mathematics: A PRISMA-Guided Review
2. Revisiting Game-Based Learning in Mathematics: Effects on Thinking, Attitudes, and Equity from a Global Perspective
3. From Understanding to Enjoyment: The Dual Impact of Game-Based Learning in Mathematics Education
4. The Role of Digital Game-Based Tools in Mathematics Education: Insights from a Systematic Review
5. Gamifying Mathematics: A Systematic Review of Pedagogical Innovations and Learning Outcomes

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Learning (GBL) has gained prominence as an approach that enhances problem-solving, reasoning, and student engagement through interactive, technology-enhanced platforms such as digital simulations, puzzles, and gamified assessments (Gundersen & Lampropoulos, 2025; Hu et al., 2022).

GBL has gained widespread attention in STEM education for its constructivist approach, real-time feedback, and ability to reduce mathematics anxiety (Moon et al., 2024; Munirah et al., 2020). While promising results are evident in high-income countries, findings from developing regions remain fragmented, complicated by varied game types, digital simulations, board games, and inconsistent research designs and outcome measures (Radkowsch et al., 2021). Prior studies have largely emphasized cognitive outcomes, with limited focus on affective domains crucial for sustaining motivation and learning success (Varas-Pavez et al., 2025). Moreover, only 15% of GBL research employs standardized tools for affective assessment (Radkowsch et al., 2021), and few explore its role in shaping emotional engagement or attitudes in mathematics learning (Lee Yan & Mohd Matore, 2023). Addressing these gaps, this review adopts PRISMA 2020 guidelines and thematic synthesis, rarely been applied in prior mathematics GBL reviews to comprehensively map cognitive and affective impacts across diverse contexts.

To address this gap, this study conducts a systematic literature review (SLR) of peer-reviewed articles published between 2018 and 2025, focusing on both cognitive (problem-solving, reasoning, conceptual understanding) and affective (motivation, attitude, engagement) outcomes of GBL in mathematics education dimensions rarely integrated in previous reviews. This dual focus offers theoretical and practical insights for developing evidence-based, emotionally responsive GBL frameworks, which are increasingly critical in the post-pandemic era marked by rapid digital and remote learning expansion (*PISA 2022 Results (Volume I)*, 2023; Szabo et al., 2020).

The 2018–2025 timeframe captures the acceleration of educational technologies and GBL adoption triggered by COVID-19, underscoring the need for a comprehensive synthesis to guide hybrid and virtual teaching models. Moreover, this review advances prior studies by rigorously applying PRISMA 2020 guidelines and thematic synthesis, ensuring methodological transparency and replicability elements often lacking in earlier GBL-focused SLRs (Radkowsch et al., 2021). Specifically, this study aims to: (1) assess GBL's impact on students' cognitive development; (2) evaluate its influence on affective domains; (3) identify key GBL implementation themes; and (4) explore contextual factors moderating GBL

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effectiveness.

METHODS

Review Type and Objectives

This study employed a systematic literature review (SLR) guided by the PRISMA 2020 protocol (Page et al., 2021), aiming to synthesize empirical evidence on the effects of Digital Game-Based Learning (DGBL) on students' cognitive (conceptual understanding, reasoning, problem-solving, critical and creative thinking) and affective outcomes (motivation, engagement, attitudes) in primary and secondary mathematics education. The review period of 2018–2025 was chosen to capture recent advancements in digital Game-Based Learning (DGBL), especially given the surge in technology adoption during and after the COVID-19 pandemic, which has significantly transformed educational practices globally.

Data Sources and Search Strategy

The literature search was conducted in Scopus, Web of Science (WoS), and ScienceDirect using Boolean operators (“AND”, “OR”) with the terms: “game-based learning” OR “gamification” AND “mathematics” OR “mathematics education” AND “cognitive domain” OR “affective domain”. The search was limited to peer-reviewed English journal articles, published between January 2018 and May 2025, available in full-text Open Access. A pilot search was first carried out to refine keywords and Boolean strings for relevance and retrieval quality. Citation tracking and grey literature were excluded to maintain methodological rigor and reduce publication bias. Figure 1 illustrates the distribution of the term “math gamification” in the Scopus database.

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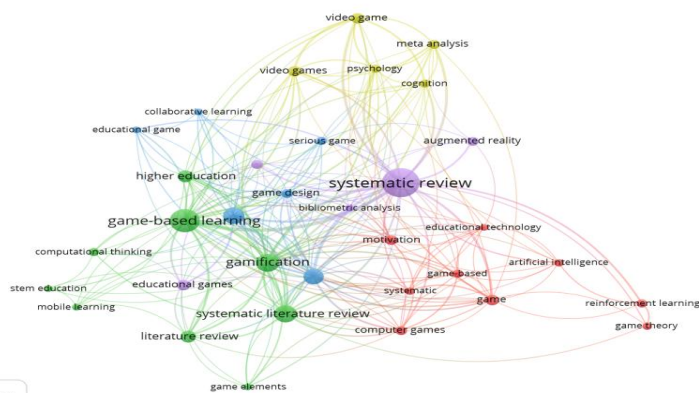




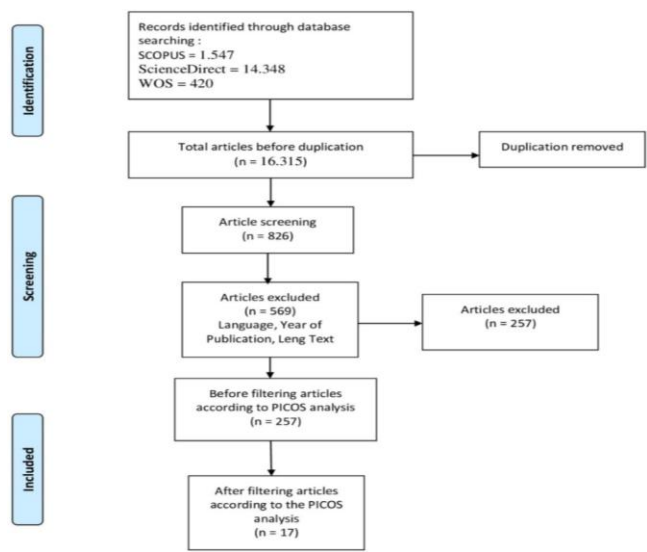
Figure 1. Distribution of the Term “Math Gamification” Based on Scopus Database Retrieval

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were established to ensure the relevance and methodological rigor of this systematic review. Included studies were empirical, focused on Digital Game-Based Learning (DGBL) in mathematics education, involved primary or secondary students, measured cognitive and/or affective outcomes using clear indicators, applied experimental or quasi-experimental designs with group comparisons, and were peer-reviewed English journal articles. Excluded studies were those involving non-digital games, special populations (e.g., students with disabilities or gifted learners) to reduce bias, as well as theoretical articles, literature reviews, editorials, book chapters, and conference papers. Additionally, studies reporting only indirect outcomes (e.g., motivation without academic performance data) or lacking full-text availability were omitted.

Screening and Selection Process

A four-stage PRISMA flow was followed: *identification*, *screening*, *eligibility*, and *inclusion*. The initial search yielded 16,315 records. After removing duplicates, 826 articles remained for title and abstract screening. Based on relevance and inclusion criteria, 257 articles proceeded to full-text assessment. Of these, 17 studies met all inclusion criteria and were retained for final synthesis. The screening process followed guidelines adapted from Margot & Kettler (2019), Mohamed Shaffril et al. (2021) and is illustrated in Figure 1.



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Figure 2. PRISMA flow diagram

Quality Appraisal

The quality of the included studies was evaluated using the CASP checklist to ensure methodological rigor, design clarity, and outcome reliability. Only studies scoring $\geq 70\%$ were included. Potential biases, such as publication and selection bias, were minimized through comprehensive database searches and multi-stage screening. Formal funnel plot analysis was omitted due to the qualitative synthesis. Two independent reviewers conducted the appraisal, resolving discrepancies through consensus to maintain objectivity.

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Data Extraction and Synthesis

This review adhered to PRISMA 2020 guidelines (Page et al., 2021) to ensure transparency and replicability. A structured coding matrix in Excel captured essential study details: authors, year, country, method, participants, intervention type, cognitive and affective outcomes, instruments, and main results. Thematic synthesis combined inductive and deductive approaches; predefined themes (cognitive vs. affective) were expanded via open coding into subthemes like reasoning, engagement, and anxiety reduction. Studies were categorized by education level, game type (digital, non-digital, gamification), and regional context (developed vs. developing), enabling pattern comparison. Two independent reviewers conducted data extraction and coding; discrepancies were resolved by consensus. Cohen’s Kappa (0.81) confirmed substantial inter-rater reliability. Due to methodological heterogeneity, meta-analysis was not performed; instead, descriptive statistics and narrative synthesis summarized findings and gaps. The themes were validated through peer debriefing to ensure trustworthiness. Table 2 summarizes the 17 included studies, highlighting intervention diversity and geographical distribution.

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Table 2. Overview of Selected Studies on Game-Based Learning in Mathematics Education

Author(s)	Year	Country	Study Design	Game Type / Approach	Learning Focus	Outcomes Measured
Kiili et al.	2018	Germany	Experimental	Digital Rational Number Game	Fractions and Rational Number Concepts	Problem-solving, Engagement
Groening & Binnewies	2019	Germany	Between-Subjects	Gamification (Digital Rewards)	Motivation and Academic Performance	Motivation, Performance
Wardani et al.	2019	Indonesia	Quasi-Experimental	Digital Media + Gamified Tasks	3D Geometry (Cube Nets)	Achievement, Student Motivation
Abidin et	2019	Malaysia	Quasi-	Points &	General	Engagement,



Author(s)	Year	Country	Study Design	Game Type / Approach	Learning Focus	Outcomes Measured
al.			Experimental	Badges	Mathematics Concepts	Performance
Barros et al.	2020	Portugal	Experimental	Gamification Serious Game (Tempoly)	Polynomial Operations	Conceptual Understanding, Accuracy
Jiménez et al.	2020	Spain	Quasi-Experimental	Digital Escape Room	Algebra Learning	Motivation, Collaboration, Problem-solving
Legaki et al.	2020	Greece	Between-Subjects	Challenge-Based Gamification	Statistical Literacy	Achievement, Cognitive Load
Yung et al.	2020	Hong Kong	Experimental	Hybrid Card & QR Game	Percentages and Fractions	Engagement, Performance
Leonardou et al.	2020	Greece	Experimental	Game-Based Assessment Tools	Learner Motivation Strategies	Engagement, Improvement
Rosillo & Montes	2021	Spain	Quasi-Experimental	Dual-Mode Escape Room	Remote Algebra Instruction	Tracking Cognitive Engagement, Motivation
Chiu & Seah	2024	Singapore	Quasi-Experimental	Contextual Gamified Tasks	Values-Based Math Teaching	Affective Dispositions, Value Alignment
Bayaga	2024	South Africa	Experimental	AI-Driven Learning Environment	Problem-Solving in Math Contexts	Reasoning, Achievement, Neural Network Performance Metrics
Zapata et al.	2024	Colombia	Quasi-Experimental	3D Augmented Reality Game	Geometry Learning via Immersion	Conceptual Understanding, Student Interest
Christopoulos et al.	2024	Greece	Experimental	3D Virtual Immersive Game	Math Skill Improvement	Spatial Reasoning, Motivation
Ding & Yu	2024	Taiwan	Between-Subjects	Serious Games vs. Game Design	Science/Math Learning vs. Game Creation	Learning Gains, Gaming Duration, Interest
Choi et al.	2025	South Korea	Quasi-Experimental	Chess-Based Educational Game	Strategic Thinking in Math	Critical Thinking, Game-Driven Reasoning
Gui et al.	2025	China	Between-Subjects	Team-Based Collaborative Game	Group Learning in Math	Group Dynamics, Collaboration, Prior Knowledge Moderation

RESULT AND DISCUSSION

Results Contextual Mapping of Selected Studies

This review synthesizes findings from 17 peer-reviewed articles selected for their methodological rigor and relevance, sourced from Scopus, WOS, and ScienceDirect databases, including Q1 (n=13), Q2 (n=2), and Q4 (n=2) journals. The studies were analyzed across four dimensions: geographical origin, publication year, research method, and target educational level. Geographically, the studies span 13 countries, offering diverse educational

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and technological contexts. Southern and Western Europe contributed the most, notably Greece (Christopoulos et al., 2024; Legaki et al., 2020; Leonardou et al., 2020) and Germany (Groening & Binnewies, 2019; Kiili et al., 2018), along with Portugal (Barros et al., 2020), Spain (Jiménez et al., 2020; Rosillo & Montes, 2021), Hong Kong (Yung et al., 2020), and Singapore (Chiu & Seah, 2024). The Global South is represented by Indonesia (Wardani et al., 2019), Malaysia (Abidin et al., 2019), South Africa (Bayaga, 2024), Colombia (Zapata et al., 2024), Taiwan (Ding & Yu, 2024), South Korea (Choi et al., 2025), and China (Gui et al., 2025).

This wide distribution reflects the global relevance of Game-Based Learning (GBL) in mathematics while revealing contextual differences. Studies from developing countries reported barriers such as limited infrastructure and teacher preparedness, whereas those from high-income nations emphasized sophisticated game design and seamless digital integration (Choi et al., 2025; Zapata et al., 2024). These disparities underscore the moderating role of local contexts in determining GBL effectiveness.

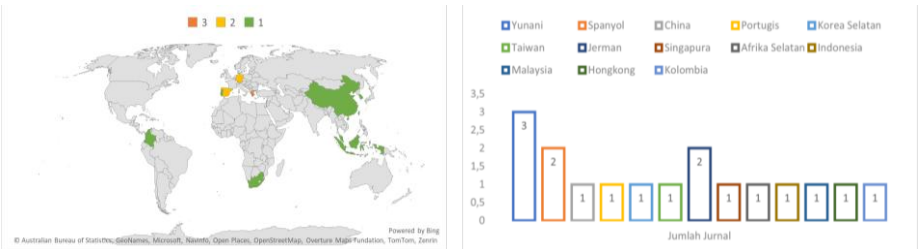


Figure 4. Distribution of Articles by Region

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Publication Trends and Game Types in Reviewed Studies

As shown in Figure 3, the reviewed studies span from 2018 to 2025 with fluctuating publication trends. The earliest study appeared in 2018 (Kiili et al., 2018), followed by three in 2019 (Abidin et al., 2019; Groening & Binnewies, 2019; Wardani et al., 2019) and five in 2020 (Barros et al., 2020; Jiménez et al., 2020; Legaki et al., 2020; Leonardou et al., 2020; Yung et al., 2020), reflecting growing interest in GBL for mathematics. Only one study was published in 2021 (Rosillo & Montes, 2021), while no eligible studies were found for 2022–2023, indicating a potential publication gap. Interest resurged in 2024 with five studies (Bayaga, 2024; Chiu & Seah, 2024; Christopoulos et al., 2024; Ding & Yu, 2024; Zapata et al., 2024), and continued with two in 2025 (Choi et al., 2025; Gui et al., 2025), suggesting renewed focus in the post-pandemic era. DGBL consistently enhanced cognitive outcomes

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like problem-solving and reasoning (Kiili et al., 2018; Barros et al., 2020), whereas gamification boosted motivation and affective engagement (Groening & Binnewies, 2019).

Regarding game types (Figure 4), three categories emerged: (1) Digital Game-Based Learning (DGBL), dominant in 11 studies (e.g., Christopoulos et al., 2024; Kiili et al., 2018); (2) Digital Gamification featured in four studies (Gui et al., 2025; Wardani et al., 2019); and (3) Non-Digital GBL applied in two studies (Bayaga, 2024; Choi et al., 2025). This distribution confirms DGBL’s prevalence, likely due to its adaptability, interactivity, and compatibility with modern educational needs.

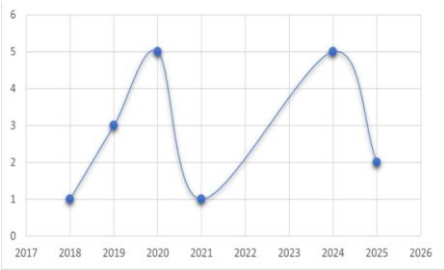


Figure 5. Distribution of Articles by Year

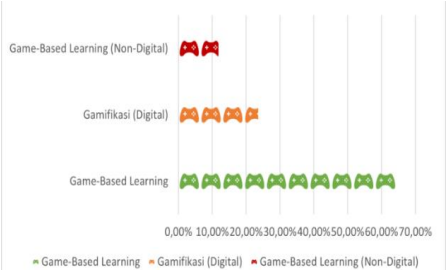


Figure 6. Distribution of Articles by Game Type

Research Design and Educational Context Distribution

As shown in Figure 7, the reviewed studies applied three main research designs: true experimental (7 studies), between-subjects experimental (4 studies), and quasi-experimental (7 studies). True experimental designs, involving random group assignment and controlled interventions, were used by Kiili et al. (2018), Barros et al. (2020), Bayaga et al. (2024), Yung et al. (2020), Leonardou et al. (2020), and Christopoulos et al. (2024). Between-subjects designs without randomization were employed in studies such as Gui et al. (2025), Ding & Yu (2024), Groening & Binnewies (2019), and Legaki et al. (2020). Quasi-experiments, lacking random assignment but involving intervention and control groups, were seen in Jimenez et al. (2020), Choi et al. (2025), Chiu & Seah (2024), Wardani et al. (2019), Abidin et al. (2019), Rosillo & Montes (2021), and Zapata et al. (2024).

Regarding educational levels (Figure 8), studies were categorized into three groups: (1) elementary/lower secondary (4 studies, e.g., Kiili et al., 2018; Choi et al., 2025; Chiu & Seah, 2024; Leonardou et al., 2020), (2) junior secondary (4 studies, e.g., Wardani et al., 2019; Abidin et al., 2019; Jimenez et al., 2020; Barros et al., 2020), and (3) combined junior–senior secondary (9 studies, e.g., Bayaga, 2024; Christopoulos et al., 2024; Ding & Yu, 2024;

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Groening & Binnewies, 2019; Gui et al., 2025; Legaki et al., 2020; Rosillo & Montes, 2021; Yung et al., 2020; Zapata et al., 2024). These classifications highlight methodological diversity and the broad application of GBL across age groups in mathematics education.

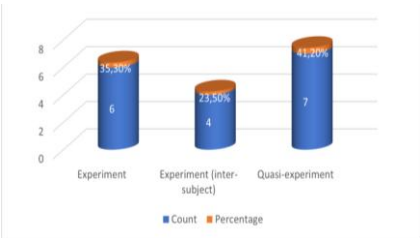


Figure 7. Distribution of articles based on research methods

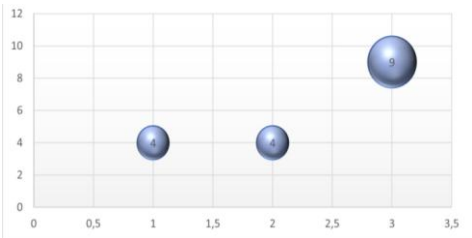


Figure 8. Distribution of articles based on education level

Thematic Trends in Game-Based Learning Research in Mathematics Education

An analysis of 17 reviewed articles identified nine key thematic areas in game-based learning (GBL) for mathematics: (1) problem-solving, (2) learning motivation, (3) general mathematics education, (4) algebra, (5) foundational skills, (6) rational numbers, (7) polynomial operations, (8) statistics, and (9) geometry (cube nets) (see Figure 9). Longer interventions (Gui et al., 2025; Zapata et al., 2024) produced more sustained cognitive and affective improvements, while short-term implementations primarily boosted immediate engagement. Problem-solving and motivation were the most frequent themes, each explored in three studies (Bayaga, 2024; Christopoulos et al., 2024; Ding & Yu, 2024; Groening & Binnewies, 2019; Gui et al., 2025; Legaki et al., 2020), emphasizing the role of GBL in enhancing reasoning skills and intrinsic motivation. General mathematics education also featured prominently (Abidin et al., 2019; Chiu & Seah, 2024; Zapata et al., 2024), alongside specific content areas such as algebra (Jiménez et al., 2020; Rosillo & Montes, 2021) and basic skills (Leonardou et al., 2020; Yung et al., 2020). Less-explored topics included rational numbers (Kiili et al., 2018), polynomials (Barros et al., 2020), statistics (Legaki et al., 2020), and geometry (Wardani et al., 2019), indicating potential for further research.

Despite GBL's promise to improve motivation and engagement, its effect on higher-order cognitive skills remains inconsistent, especially in short-duration or low-resource contexts. This suggests that GBL success depends not only on game design but also on systemic factors like infrastructure, teacher readiness, and cultural perceptions of technology (Ding & Yu, 2024; Gui et al., 2025). Moreover, the limited use of standardized affective

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measures (Radkowsch et al., 2021) raises concerns about the validity of affective outcome assessments. The underrepresentation of themes such as statistics, spatial geometry, and polynomial operations highlights the need for broader GBL content coverage in future studies.

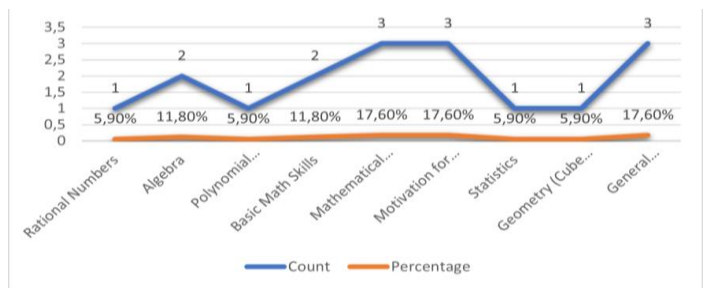


Figure 9. presents the distribution of articles based on their respective research topics.

Discussion

The Impact of Game-Based Learning (GBL) on Students’ Cognitive Domain in Mathematics Education.

Analysis of 17 reviewed articles consistently shows that GBL positively impacts students’ cognitive abilities in mathematics, particularly in enhancing conceptual understanding, problem-solving, and higher-order thinking skills such as critical and creative thinking. Kiili et al. (2018) demonstrated that game metrics could predict learning outcomes, with students outperforming control groups in rational number tasks. Similarly, Jimenez et al. (2020) and Barros et al. (2020) reported that digital games like Escape Room and Tempoly significantly improved both engagement and achievement in algebra and polynomial operations. GBL also enhances problem-solving abilities, especially among students with high prior knowledge in collaborative settings (Gui et al., 2025). Bayaga et al. (2024) found that AI-based digital GBL improved thinking skills. Visual-rich content, such as geometry and 3D objects, further benefits from GBL through digital and AR platforms (Wardani et al., 2019; Zapata et al., 2024), while hybrid models (Rosillo & Montes, 2021; Yung et al., 2020) yield positive post-test outcomes across diverse instructional formats.

From a pedagogical perspective, game-based challenges in statistics (Legaki et al., 2020) and reward systems (Leonardou et al., 2020) enhance cognitive performance, supported by immersive 3D technologies (Christopoulos et al., 2024). These findings align with Constructivist Learning Theory, emphasizing knowledge construction via active, engaging

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tasks, and with Cognitive Load Theory, where well-designed multimodal content facilitates understanding, especially in spatial domains like geometry. However, variations in research settings, sample sizes, and educational contexts limit broad generalization. Factors such as technological infrastructure, teacher readiness, and cultural attitudes toward digital learning may influence GBL effectiveness, especially in resource-constrained environments. Future research should address long-term impacts, skill transferability across mathematical domains, and differential effects on diverse learner profiles.

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The Impact of Game-Based Learning (GBL) on Students' Affective Domain in Mathematics Education.

Game-Based Learning (GBL) positively influences students' affective domain by enhancing motivation, emotional engagement, positive attitudes, and reducing mathematics anxiety, as reported in seven of the 17 reviewed studies. These improvements align with Self-Determination Theory (Ryan & Deci, 2020), which highlights autonomy, competence, and relatedness as drivers of intrinsic motivation. Positive feedback, reward systems, and challenge-based mechanics (Jiménez et al., 2020; Leonardou et al., 2019) were key factors meeting these psychological needs. For example, Jimenez et al. (2020) demonstrated that Digital Escape Rooms not only improved algebra outcomes but also increased student motivation. Similarly, Groening & Binnewies (2019) found gamification elements like badges and leaderboards enhanced engagement and confidence, while Leonardou et al. (2019) showed that well-designed feedback reshaped students' perception of mathematics as enjoyable and stimulating. Choi et al. (2025) reported that non-digital chess-based GBL fostered active engagement and competitive spirit. Studies using AR and dual-mode escape rooms (Rosillo & Montes, 2021; Zapata et al., 2024) provided immersive experiences, promoting comfort and interest in mathematics.

However, some studies (Ding & Yu, 2024) only briefly addressed affective outcomes without standardized instruments, limiting result comparability. Variations in game duration, complexity, and contextual relevance may explain inconsistencies. The general trend suggests GBL enhances motivation and reduces anxiety, but reliance on self-reports raises concerns of bias. Future research should employ multi-method assessments, such as behavioral and physiological measures, for more valid affective evaluation.

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Key Themes in the Implementation of Game-Based Learning (GBL)

This systematic review identifies four key themes that bridge cognitive, affective, and contextual aspects of GBL in mathematics education and integrative perspective rarely



emphasized in prior studies. These themes reflect prevailing trends, existing gaps, and opportunities for future pedagogical refinement.

1. **Dominance of Digital Platforms** Digital platforms dominate GBL implementation, with 10 of 17 studies employing tools such as escape rooms (Jiménez et al., 2020; Zapata et al., 2024), 3D virtual environments (Christopoulos et al., 2024), gamification systems (Leonardou et al., 2020), and AR/AI-based simulations (Bayaga, 2024; Yung et al., 2020). These studies affirm the central role of technology in enhancing engagement, interactivity, and real-time feedback, aligning with 21st-century learning demands.
2. **Focus on Problem-Solving and Higher-Order Thinking.** Nine studies emphasized problem-solving and critical thinking, particularly at the upper secondary level, where students are more prepared for complex, challenge-based tasks. GBL was strategically employed to develop analytical reasoning and conceptual depth through interactive problem scenarios (Barros et al., 2020; Gui et al., 2025).
3. **Enhancing Motivation and Engagement.** Seven studies highlighted GBL’s effectiveness in boosting motivation and positive attitudes towards mathematics. Elements such as rewards, instant feedback, and collaborative challenges (Choi et al., 2025; Groening & Binnewies, 2019; Jiménez et al., 2020) fostered intrinsic motivation, emotional involvement, and classroom enthusiasm.
4. **Global Adoption and Contextual Variations.** The reviewed studies spanned diverse regions of Europe, Asia, Africa, and Latin America, demonstrating GBL’s adaptability across cultures and educational systems (Rosillo & Montes, 2021; Zapata et al., 2024). These variations reflect differences in technological readiness, curriculum structures, and cultural values, shaping both implementation and outcomes.

However, a notable limitation is the predominance of short-term interventions, raising concerns about the sustainability of GBL’s cognitive and affective benefits. This highlights the need for longitudinal research to evaluate its long-term impact on mathematical learning outcomes.

Contextual Factors Influencing the Effectiveness of Game-Based Learning (GBL)

The success of GBL in mathematics education is shaped not only by game type but also by key contextual factors identified in 17 reviewed studies: student characteristics, game design, intervention duration, and teacher readiness with infrastructure support.

1. **Student Characteristics** Students’ prior knowledge and metacognitive skills influence GBL outcomes, as demonstrated by Gui et al. (2025), who found that learners with stronger

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prior knowledge performed better in collaborative settings. This underscores the importance of adapting GBL to students' readiness levels, aligning with Constructivist Learning Theory.

2. Type and Design of Games. GBL effectiveness depends on the game's format: digital GBL (e.g., AR, 3D simulations) fosters conceptual understanding and engagement (Kiili et al., 2018; Zapata et al., 2024), digital gamification (e.g., points, badges) boosts routine task motivation (Groening & Binnewies, 2019), while non-digital GBL (e.g., chess games) enhances interaction and critical thinking, especially in low-tech settings (Choi et al., 2025). Thus, game choice must align with learners' needs and resource availability (Zapata et al., 2024).
3. Duration and Intensity of Intervention. Short-term GBL interventions increase motivation but yield transient effects (Leonardou et al., 2020); longer, repeated applications produce more stable cognitive and problem-solving gains (Gui et al., 2025; Zapata et al., 2024). However, inconsistent reporting on duration limits cross-study comparability, emphasizing the need for standardized intervention descriptions.
4. Teacher Readiness and Infrastructure. Teacher competence and infrastructure quality are crucial. Lack of training and limited digital skills hinder GBL use (Wardani et al., 2019), as does insufficient technological access (Ding & Yu, 2024). Successful GBL implementations require technical support, policy backing, and institutional commitment.

In sum, while GBL holds potential to enhance cognitive and affective outcomes in mathematics, its success relies heavily on these contextual factors. Adaptive strategies, mixed-methods research, and validated tools are needed to capture long-term impacts, especially in resource-limited contexts. Policymakers should promote low-cost, culturally relevant non-digital GBL to bridge technological gaps, and future studies should explore moderators such as socio-economic status, digital literacy, and gender.

CONCLUSION

This systematic review synthesized findings from 17 empirical studies (2018–2025) on the impact of Game-Based Learning (GBL) in mathematics education. Results consistently showed that GBL enhances cognitive skills such as conceptual understanding, problem-solving, and higher-order thinking (critical and creative), improving performance in algebra, statistics, and geometry. Digital tools like escape rooms, AR/3D environments, and gamified platforms proved particularly effective in promoting deep learning and engagement. GBL also

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positively influenced affective outcomes by increasing motivation, reducing math anxiety, and fostering positive attitudes. However, most studies lacked standardized, psychometrically sound instruments for measuring affective impacts, indicating a need for stronger methodological rigor.

Contextual factors, student characteristics, game design quality, intervention duration, and teacher readiness were critical, with game design and teacher competence as key determinants. A disparity remains between digital GBL in well-resourced settings and the relevance of non-digital games in limited-resource environments, reflecting a global digital divide. Overall, GBL offers a promising approach to integrating cognitive and affective learning. Future efforts should focus on contextualized game design, comprehensive teacher training, and equitable technology access, aligning with Indonesia's *Kurikulum Merdeka* and 21st-century education goals. Further research is needed to establish standardized affective assessment tools and evaluate GBL's long-term impacts across varied contexts.

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ACKNOWLEDGMENTS

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Systematic Review on the Impact of Game-Based Learning on Students' Cognitive and Affective Domains

ABSTRACT

This study employed a Systematic Literature Review (SLR) following the PRISMA 2020 guidelines to evaluate the impact of Game-Based Learning (GBL) on students' cognitive and affective domains in mathematics education, synthesizing evidence from 17 empirical studies published between 2018 and 2025. The findings consistently indicate that GBL significantly improves cognitive outcomes, including conceptual understanding, problem-solving skills, and critical thinking abilities, particularly when supported by digital tools such as augmented reality, 3D escape rooms, and gamified platforms. In addition, GBL positively influences affective outcomes by increasing student motivation and fostering more favorable attitudes toward mathematics, while also reducing math anxiety. However, assessments of affective domains remain less standardized compared to those of cognitive outcomes. Key contextual factors such as students' prior knowledge, the quality of game design, intervention duration, and teacher preparedness were found to be critical in determining GBL effectiveness. The review highlights the dominance of digital GBL in resource-rich environments, while also recognizing the potential of non-digital adaptations in low-resource contexts. Drawing on diverse international evidence, this review underscores GBL's potential as an innovative pedagogical strategy that effectively integrates cognitive and affective learning. Practical recommendations include culturally responsive game design, comprehensive teacher training, and equitable access to technology to ensure successful GBL implementation across varied educational settings.

KEYWORDS

Game-Based Learning; Mathematics Education; Cognitive Domain; Affective Domain; Systematic Review

INTRODUCTION

Mathematics education, both in developed and developing countries like Indonesia, is fundamental in preparing learners for the demands of the 21st century marked by digitalization, automation, and complex problem-solving (Szabo et al., 2020; Yulianto et al., 2024). However, despite its importance, mathematics often triggers anxiety and disengagement, leading to low achievement worldwide, especially in developing regions where PISA and TIMSS scores remain below the OECD average (PISA 2022 Results (Volume I), 2023). These challenges call for pedagogical innovation beyond curriculum reform, emphasizing cognitive and affective integration. Effective learning requires student-centered strategies that build reasoning, conceptual fluency, and motivation. In response, Game-Based

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Learning (GBL) has gained prominence as an approach that enhances problem-solving, reasoning, and student engagement through interactive, technology-enhanced platforms such as digital simulations, puzzles, and gamified assessments (Gundersen & Lampropoulos, 2025; Hu et al., 2022).

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GBL has gained widespread attention in STEM education for its constructivist approach, real-time feedback, and ability to reduce mathematics anxiety (Moon et al., 2024; Munirah et al., 2020). While promising results are evident in high-income countries, findings from developing regions remain fragmented, complicated by varied game types, digital simulations, board games, and inconsistent research designs and outcome measures (Radkowsch et al., 2021). Prior studies have largely emphasized cognitive outcomes, with limited focus on affective domains crucial for sustaining motivation and learning success (Varas-Pavez et al., 2025). Moreover, only 15% of GBL research employs standardized tools for affective assessment (Radkowsch et al., 2021), and few explore its role in shaping emotional engagement or attitudes in mathematics learning (Lee Yan & Mohd Matore, 2023). Addressing these gaps, this review adopts PRISMA 2020 guidelines and thematic synthesis, rarely been applied in prior mathematics GBL reviews to comprehensively map cognitive and affective impacts across diverse contexts.

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To address this gap, this study conducts a systematic literature review (SLR) of peer-reviewed articles published between 2018 and 2025, focusing on both cognitive (problem-solving, reasoning, conceptual understanding) and affective (motivation, attitude, engagement) outcomes of GBL in mathematics education dimensions rarely integrated in previous reviews. This dual focus offers theoretical and practical insights for developing evidence-based, emotionally responsive GBL frameworks, which are increasingly critical in the post-pandemic era marked by rapid digital and remote learning expansion (*PISA 2022 Results (Volume I)*, 2023; Szabo et al., 2020).

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The 2018–2025 timeframe captures the acceleration of educational technologies and GBL adoption triggered by COVID-19, underscoring the need for a comprehensive synthesis to guide hybrid and virtual teaching models. Moreover, this review advances prior studies by rigorously applying PRISMA 2020 guidelines and thematic synthesis, ensuring methodological transparency and replicability elements often lacking in earlier GBL-focused SLRs (Radkowsch et al., 2021). Specifically, this study aims to: (1) assess GBL’s impact on students’ cognitive development; (2) evaluate its influence on affective domains; (3) identify key GBL implementation themes; and (4) explore contextual factors moderating GBL

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METHODS

This study employed a systematic literature review (SLR) guided by the PRISMA 2020 protocol (Page et al., 2021), aiming to synthesize empirical evidence on the effects of Digital Game-Based Learning (DGBL) on students' cognitive (conceptual understanding, reasoning, problem-solving, critical and creative thinking) and affective outcomes (motivation, engagement, attitudes) in primary and secondary mathematics education. The review period of 2018–2025 was chosen to capture recent advancements in digital Game-Based Learning (DGBL), especially given the surge in technology adoption during and after the COVID-19 pandemic, which has significantly transformed educational practices globally.

The literature search was conducted in Scopus, Web of Science (WoS), and ScienceDirect using Boolean operators (“AND”, “OR”) with the terms: “game-based learning” OR “gamification” AND “mathematics” OR “mathematics education” AND “cognitive domain” OR “affective domain”. The search was limited to peer-reviewed English journal articles, published between January 2018 and May 2025, available in full-text Open Access. A pilot search was first carried out to refine keywords and Boolean strings for relevance and retrieval quality. Citation tracking and grey literature were excluded to maintain methodological rigor and reduce publication bias. Figure 1 illustrates the distribution of the term “math gamification” in the Scopus database.





Figure 1. Distribution of the Term “Math Gamification” Based on Scopus Database Retrieval

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were established to ensure the relevance and methodological rigor of this systematic review. Included studies were empirical, focused on Digital Game-Based Learning (DGBL) in mathematics education, involved primary or secondary students, measured cognitive and/or affective outcomes using clear indicators, applied experimental or quasi-experimental designs with group comparisons, and were peer-reviewed English journal articles. Excluded studies were those involving non-digital games, special populations (e.g., students with disabilities or gifted learners) to reduce bias, as well as theoretical articles, literature reviews, editorials, book chapters, and conference papers. Additionally, studies reporting only indirect outcomes (e.g., motivation without academic performance data) or lacking full-text availability were omitted.

Screening and Selection Process

A four-stage PRISMA flow was followed: *identification*, *screening*, *eligibility*, and *inclusion*. The initial search yielded 16,315 records. After removing duplicates, 826 articles remained for title and abstract screening. Based on relevance and inclusion criteria, 257 articles proceeded to full-text assessment. Of these, 17 studies met all inclusion criteria and were retained for final synthesis. The screening process followed guidelines adapted from Margot & Kettler (2019), Mohamed Shaffril et al. (2021) and is illustrated in Figure 1.

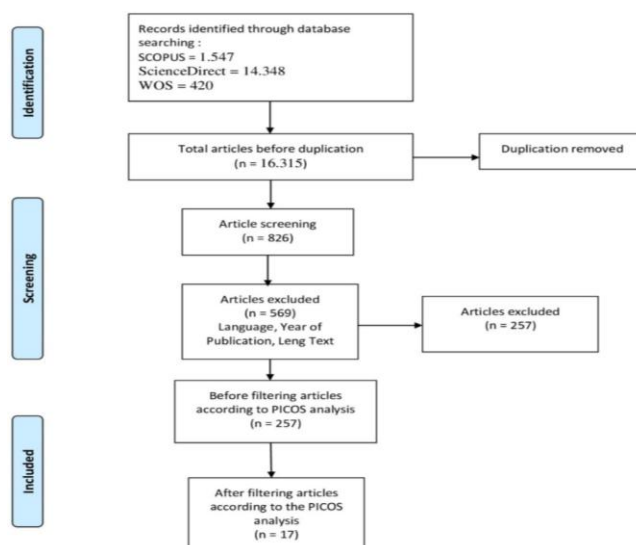




Figure 2. PRISMA flow diagram

Quality Appraisal

The quality of the included studies was evaluated using the CASP checklist to ensure methodological rigor, design clarity, and outcome reliability. Only studies scoring $\geq 70\%$ were included. Potential biases, such as publication and selection bias, were minimized through comprehensive database searches and multi-stage screening. Formal funnel plot analysis was omitted due to the qualitative synthesis. Two independent reviewers conducted the appraisal, resolving discrepancies through consensus to maintain objectivity.

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Data Extraction and Synthesis

This review adhered to PRISMA 2020 guidelines (Page et al., 2021) to ensure transparency and replicability. A structured coding matrix in Excel captured essential study details: authors, year, country, method, participants, intervention type, cognitive and affective outcomes, instruments, and main results. Thematic synthesis combined inductive and deductive approaches; predefined themes (cognitive vs. affective) were expanded via open coding into subthemes like reasoning, engagement, and anxiety reduction. Studies were categorized by education level, game type (digital, non-digital, gamification), and regional context (developed vs. developing), enabling pattern comparison. Two independent reviewers conducted data extraction and coding; discrepancies were resolved by consensus. Cohen’s Kappa (0.81) confirmed substantial inter-rater reliability. Due to methodological heterogeneity, meta-analysis was not performed; instead, descriptive statistics and narrative synthesis summarized findings and gaps. Themes were validated through peer debriefing to ensure trustworthiness. Table 2 summarizes the 17 included studies, highlighting intervention diversity and geographical distribution.

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Table 2. Overview of Selected Studies on Game-Based Learning in Mathematics Education

Author(s)	Year	Country	Study Design	Game Type / Approach	Learning Focus	Outcomes Measured
Kiili et al.	2018	Germany	Experimental	Digital Rational Number Game	Fractions and Rational Number Concepts	Problem-solving, Engagement
Groening & Binnewies	2019	Germany	Between-Subjects	Gamification (Digital Rewards)	Motivation and Academic Performance	Motivation, Performance
Wardani et al.	2019	Indonesia	Quasi-Experimental	Digital Media + Gamified Tasks	3D Geometry (Cube Nets)	Achievement, Student Motivation
Abidin et	2019	Malaysia	Quasi-	Points &	General	Engagement,



Author(s)	Year	Country	Study Design	Game Type / Approach	Learning Focus	Outcomes Measured
al.			Experimental	Badges	Mathematics Concepts	Performance
Barros et al.	2020	Portugal	Experimental	Gamification Serious Game (Tempoly)	Polynomial Operations	Conceptual Understanding, Accuracy
Jiménez et al.	2020	Spain	Quasi-Experimental	Digital Escape Room	Algebra Learning	Motivation, Collaboration, Problem-solving
Legaki et al.	2020	Greece	Between-Subjects	Challenge-Based Gamification	Statistical Literacy	Achievement, Cognitive Load
Yung et al.	2020	Hong Kong	Experimental	Hybrid Card & QR Game	Percentages and Fractions	Engagement, Performance
Leonardou et al.	2020	Greece	Experimental	Game-Based Assessment Tools	Learner Motivation Strategies	Engagement, Improvement
Rosillo & Montes	2021	Spain	Quasi-Experimental	Dual-Mode Escape Room	Remote Algebra Instruction	Tracking Cognitive Engagement, Motivation
Chiu & Seah	2024	Singapore	Quasi-Experimental	Contextual Gamified Tasks	Values-Based Math Teaching	Affective Dispositions, Value Alignment
Bayaga	2024	South Africa	Experimental	AI-Driven Learning Environment	Problem-Solving in Math Contexts	Reasoning, Achievement, Neural Network Performance Metrics
Zapata et al.	2024	Colombia	Quasi-Experimental	3D Augmented Reality Game	Geometry Learning via Immersion	Conceptual Understanding, Student Interest
Christopoulos et al.	2024	Greece	Experimental	3D Virtual Immersive Game	Math Skill Improvement	Spatial Reasoning, Motivation
Ding & Yu	2024	Taiwan	Between-Subjects	Serious Games vs. Game Design	Science/Math Learning vs. Game Creation	Learning Gains, Gaming Duration, Interest
Choi et al.	2025	South Korea	Quasi-Experimental	Chess-Based Educational Game	Strategic Thinking in Math	Critical Thinking, Game-Driven Reasoning
Gui et al.	2025	China	Between-Subjects	Team-Based Collaborative Game	Group Learning in Math	Group Dynamics, Collaboration, Prior Knowledge Moderation

RESULT AND DISCUSSION

Results Contextual Mapping of Selected Studies

This review synthesizes findings from 17 peer-reviewed articles selected for their methodological rigor and relevance, sourced from Scopus, WOS, and ScienceDirect databases, including Q1 (n=13), Q2 (n=2), and Q4 (n=2) journals. The studies were analyzed across four dimensions: geographical origin, publication year, research method, and target educational level. Geographically, the studies span 13 countries, offering diverse educational

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and technological contexts. Southern and Western Europe contributed the most, notably Greece (Christopoulos et al., 2024; Legaki et al., 2020; Leonardou et al., 2020) and Germany (Groening & Binnewies, 2019; Kiili et al., 2018), along with Portugal (Barros et al., 2020), Spain (Jiménez et al., 2020; Rosillo & Montes, 2021), Hong Kong (Yung et al., 2020), and Singapore (Chiu & Seah, 2024). The Global South is represented by Indonesia (Wardani et al., 2019), Malaysia (Abidin et al., 2019), South Africa (Bayaga, 2024), Colombia (Zapata et al., 2024), Taiwan (Ding & Yu, 2024), South Korea (Choi et al., 2025), and China (Gui et al., 2025).

This wide distribution reflects the global relevance of Game-Based Learning (GBL) in mathematics while revealing contextual differences. Studies from developing countries reported barriers such as limited infrastructure and teacher preparedness, whereas those from high-income nations emphasized sophisticated game design and seamless digital integration (Choi et al., 2025; Zapata et al., 2024). These disparities underscore the moderating role of local contexts in determining GBL effectiveness.

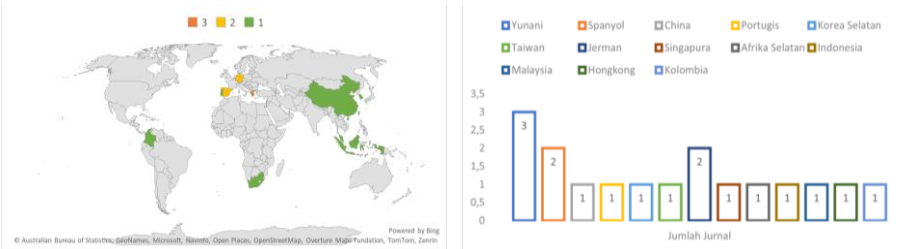


Figure 4. Distribution of Articles by Region

Publication Trends and Game Types in Reviewed Studies

As shown in Figure 3, the reviewed studies span from 2018 to 2025 with fluctuating publication trends. The earliest study appeared in 2018 (Kiili et al., 2018), followed by three in 2019 (Abidin et al., 2019; Groening & Binnewies, 2019; Wardani et al., 2019) and five in 2020 (Barros et al., 2020; Jiménez et al., 2020; Legaki et al., 2020; Leonardou et al., 2020; Yung et al., 2020), reflecting growing interest in GBL for mathematics. Only one study was published in 2021 (Rosillo & Montes, 2021), while no eligible studies were found for 2022–2023, indicating a potential publication gap. Interest resurged in 2024 with five studies (Bayaga, 2024; Chiu & Seah, 2024; Christopoulos et al., 2024; Ding & Yu, 2024; Zapata et al., 2024), and continued with two in 2025 (Choi et al., 2025; Gui et al., 2025), suggesting renewed focus in the post-pandemic era. DGBL consistently enhanced cognitive outcomes



like problem-solving and reasoning (Kiili et al., 2018; Barros et al., 2020), whereas gamification boosted motivation and affective engagement (Groening & Binnewies, 2019).

Regarding game types (Figure 4), three categories emerged: (1) Digital Game-Based Learning (DGBL), dominant in 11 studies (e.g., Christopoulos et al., 2024; Kiili et al., 2018); (2) Digital Gamification featured in four studies (Gui et al., 2025; Wardani et al., 2019); and (3) Non-Digital GBL applied in two studies (Bayaga, 2024; Choi et al., 2025). This distribution confirms DGBL's prevalence, likely due to its adaptability, interactivity, and compatibility with modern educational needs.

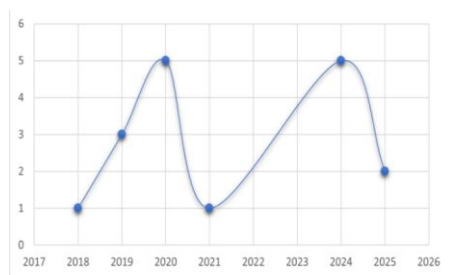


Figure 5. Distribution of Articles by Year

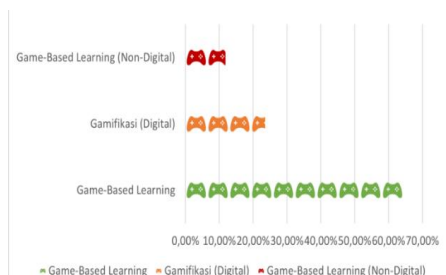


Figure 6. Distribution of Articles by Game Type

Research Design and Educational Context Distribution

As shown in Figure 7, the reviewed studies applied three main research designs: true experimental (7 studies), between-subjects experimental (4 studies), and quasi-experimental (7 studies). True experimental designs, involving random group assignment and controlled interventions, were used by Kiili et al. (2018), Barros et al. (2020), Bayaga et al. (2024), Yung et al. (2020), Leonardou et al. (2020), and Christopoulos et al. (2024). Between-subjects designs without randomization were employed in studies such as Gui et al. (2025), Ding & Yu (2024), Groening & Binnewies (2019), and Legaki et al. (2020). Quasi-experiments, lacking random assignment but involving intervention and control groups, were seen in Jimenez et al. (2020), Choi et al. (2025), Chiu & Seah (2024), Wardani et al. (2019), Abidin et al. (2019), Rosillo & Montes (2021), and Zapata et al. (2024).

Regarding educational levels (Figure 8), studies were categorized into three groups: (1) elementary/lower secondary (4 studies, e.g., Kiili et al., 2018; Choi et al., 2025; Chiu & Seah, 2024; Leonardou et al., 2020), (2) junior secondary (4 studies, e.g., Wardani et al., 2019; Abidin et al., 2019; Jimenez et al., 2020; Barros et al., 2020), and (3) combined junior–senior secondary (9 studies, e.g., Bayaga, 2024; Christopoulos et al., 2024; Ding & Yu, 2024;



Groening & Binnewies, 2019; Gui et al., 2025; Legaki et al., 2020; Rosillo & Montes, 2021; Yung et al., 2020; Zapata et al., 2024). These classifications highlight methodological diversity and the broad application of GBL across age groups in mathematics education.

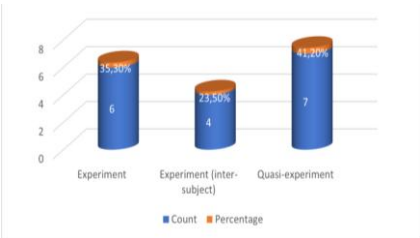


Figure 7. Distribution of articles based on research methods

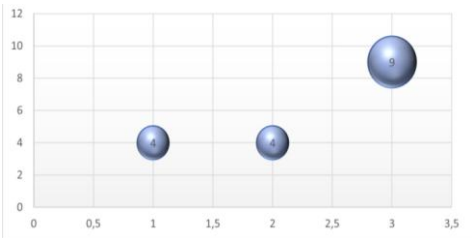


Figure 8. Distribution of articles based on education level

Thematic Trends in Game-Based Learning Research in Mathematics Education

An analysis of 17 reviewed articles identified nine key thematic areas in game-based learning (GBL) for mathematics: (1) problem-solving, (2) learning motivation, (3) general mathematics education, (4) algebra, (5) foundational skills, (6) rational numbers, (7) polynomial operations, (8) statistics, and (9) geometry (cube nets) (see Figure 9). Longer interventions (Gui et al., 2025; Zapata et al., 2024) produced more sustained cognitive and affective improvements, while short-term implementations primarily boosted immediate engagement. Problem-solving and motivation were the most frequent themes, each explored in three studies (Bayaga, 2024; Christopoulos et al., 2024; Ding & Yu, 2024; Groening & Binnewies, 2019; Gui et al., 2025; Legaki et al., 2020), emphasizing the role of GBL in enhancing reasoning skills and intrinsic motivation. General mathematics education also featured prominently (Abidin et al., 2019; Chiu & Seah, 2024; Zapata et al., 2024), alongside specific content areas such as algebra (Jiménez et al., 2020; Rosillo & Montes, 2021) and basic skills (Leonardou et al., 2020; Yung et al., 2020). Less-explored topics included rational numbers (Kiili et al., 2018), polynomials (Barros et al., 2020), statistics (Legaki et al., 2020), and geometry (Wardani et al., 2019), indicating potential for further research.

Despite GBL’s promise in improving motivation and engagement, its effect on higher-order cognitive skills remains inconsistent, especially in short-duration or low-resource contexts. This suggests that GBL success depends not only on game design but also on systemic factors like infrastructure, teacher readiness, and cultural perceptions of technology (Ding & Yu, 2024; Gui et al., 2025). Moreover, the limited use of standardized affective

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measures (Radkowsch et al., 2021) raises concerns about the validity of affective outcome assessments. The underrepresentation of themes such as statistics, spatial geometry, and polynomial operations highlights the need for broader GBL content coverage in future studies.

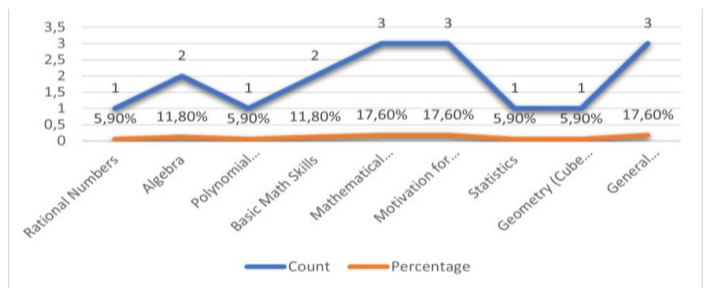


Figure 9. presents the distribution of articles based on their respective research topics.

Discussion

The Impact of Game-Based Learning (GBL) on Students’ Cognitive Domain in Mathematics Education.

Analysis of 17 reviewed articles consistently shows that GBL positively impacts students’ cognitive abilities in mathematics, particularly in enhancing conceptual understanding, problem-solving, and higher-order thinking skills such as critical and creative thinking. Kiili et al. (2018) demonstrated that game metrics could predict learning outcomes, with students outperforming control groups in rational number tasks. Similarly, Jimenez et al. (2020) and Barros et al. (2020) reported that digital games like Escape Room and Tempoly significantly improved both engagement and achievement in algebra and polynomial operations. GBL also enhances problem-solving abilities, especially among students with high prior knowledge in collaborative settings (Gui et al., 2025). Bayaga et al. (2024) found that AI-based digital GBL improved thinking skills. Visual-rich content, such as geometry and 3D objects, further benefits from GBL through digital and AR platforms (Wardani et al., 2019; Zapata et al., 2024), while hybrid models (Rosillo & Montes, 2021; Yung et al., 2020) yield positive post-test outcomes across diverse instructional formats.

From a pedagogical perspective, game-based challenges in statistics (Legaki et al., 2020) and reward systems (Leonardou et al., 2020) enhance cognitive performance, supported by immersive 3D technologies (Christopoulos et al., 2024). These findings align with Constructivist Learning Theory, emphasizing knowledge construction via active, engaging



tasks, and with Cognitive Load Theory, where well-designed multimodal content facilitates understanding, especially in spatial domains like geometry. However, variations in research settings, sample sizes, and educational contexts limit broad generalization. Factors such as technological infrastructure, teacher readiness, and cultural attitudes toward digital learning may influence GBL effectiveness, especially in resource-constrained environments. Future research should address long-term impacts, skill transferability across mathematical domains, and differential effects on diverse learner profiles.

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The Impact of Game-Based Learning (GBL) on Students' Affective Domain in Mathematics Education.

Game-Based Learning (GBL) positively influences students' affective domain by enhancing motivation, emotional engagement, positive attitudes, and reducing mathematics anxiety, as reported in seven of the 17 reviewed studies. These improvements align with Self-Determination Theory (Ryan & Deci, 2020), which highlights autonomy, competence, and relatedness as drivers of intrinsic motivation. Positive feedback, reward systems, and challenge-based mechanics (Jiménez et al., 2020; Leonardou et al., 2019) were key factors meeting these psychological needs. For example, Jimenez et al. (2020) demonstrated that Digital Escape Rooms not only improved algebra outcomes but also increased student motivation. Similarly, Groening & Binnewies (2019) found gamification elements like badges and leaderboards enhanced engagement and confidence, while Leonardou et al. (2019) showed that well-designed feedback reshaped students' perception of mathematics as enjoyable and stimulating. Choi et al. (2025) reported that non-digital chess-based GBL fostered active engagement and a competitive spirit. Studies using AR and dual-mode escape rooms (Rosillo & Montes, 2021; Zapata et al., 2024) provided immersive experiences, promoting comfort and interest in mathematics.

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However, some studies (Ding & Yu, 2024) only briefly addressed affective outcomes without standardized instruments, limiting result comparability. Variations in game duration, complexity, and contextual relevance may explain inconsistencies. The general trend suggests GBL enhances motivation and reduces anxiety, but reliance on self-reports raises concerns of bias. Future research should employ multi-method assessments, such as behavioral and physiological measures, for more valid affective evaluation.

Key Themes in the Implementation of Game-Based Learning (GBL)

This systematic review identifies four key themes that bridge cognitive, affective, and contextual aspects of GBL in mathematics education an integrative perspective rarely



emphasized in prior studies. These themes reflect prevailing trends, existing gaps, and opportunities for future pedagogical refinement.

1. **Dominance of Digital Platforms** Digital platforms dominate GBL implementation, with 10 of 17 studies employing tools such as escape rooms (Jiménez et al., 2020; Zapata et al., 2024), 3D virtual environments (Christopoulos et al., 2024), gamification systems (Leonardou et al., 2020), and AR/AI-based simulations (Bayaga, 2024; Yung et al., 2020). These studies affirm the central role of technology in enhancing engagement, interactivity, and real-time feedback, aligning with 21st-century learning demands.
2. **Focus on Problem-Solving and Higher-Order Thinking.** Nine studies emphasized problem-solving and critical thinking, particularly at the upper secondary level, where students are more prepared for complex, challenge-based tasks. GBL was strategically employed to develop analytical reasoning and conceptual depth through interactive problem scenarios (Barros et al., 2020; Gui et al., 2025).
3. **Enhancing Motivation and Engagement.** Seven studies highlighted GBL's effectiveness in boosting motivation and positive attitudes towards mathematics. Elements such as rewards, instant feedback, and collaborative challenges (Choi et al., 2025; Groening & Binnewies, 2019; Jiménez et al., 2020) fostered intrinsic motivation, emotional involvement, and classroom enthusiasm.
4. **Global Adoption and Contextual Variations.** The reviewed studies spanned diverse regions of Europe, Asia, Africa, and Latin America, demonstrating GBL's adaptability across cultures and educational systems (Rosillo & Montes, 2021; Zapata et al., 2024). These variations reflect differences in technological readiness, curriculum structures, and cultural values, shaping both implementation and outcomes.

However, a notable limitation is the predominance of short-term interventions, raising concerns about the sustainability of GBL's cognitive and affective benefits. This highlights the need for longitudinal research to evaluate its long-term impact on mathematical learning outcomes.

Contextual Factors Influencing the Effectiveness of Game-Based Learning (GBL)

The success of GBL in mathematics education is shaped not only by game type but also by key contextual factors identified in 17 reviewed studies: student characteristics, game design, intervention duration, and teacher readiness with infrastructure support.

1. **Student Characteristics** Students' prior knowledge and metacognitive skills influence GBL outcomes, as demonstrated by Gui et al. (2025), who found that learners with stronger



prior knowledge performed better in collaborative settings. This underscores the importance of adapting GBL to students' readiness levels, aligning with Constructivist Learning Theory.

2. Type and Design of Games. GBL effectiveness depends on the game's format: digital GBL (e.g., AR, 3D simulations) fosters conceptual understanding and engagement (Kiili et al., 2018; Zapata et al., 2024), digital gamification (e.g., points, badges) boosts routine task motivation (Groening & Binnewies, 2019), while non-digital GBL (e.g., chess games) enhances interaction and critical thinking, especially in low-tech settings (Choi et al., 2025). Thus, game choice must align with learners' needs and resource availability (Zapata et al., 2024).
3. Duration and Intensity of Intervention. Short-term GBL interventions increase motivation but yield transient effects (Leonardou et al., 2020); longer, repeated applications produce more stable cognitive and problem-solving gains (Gui et al., 2025; Zapata et al., 2024). However, inconsistent reporting on duration limits cross-study comparability, emphasizing the need for standardized intervention descriptions.
4. Teacher Readiness and Infrastructure. Teacher competence and infrastructure quality are crucial. Lack of training and limited digital skills hinder GBL use (Wardani et al., 2019), as does insufficient technological access (Ding & Yu, 2024). Successful GBL implementations require technical support, policy backing, and institutional commitment.

In sum, while GBL holds potential to enhance cognitive and affective outcomes in mathematics, its success relies heavily on these contextual factors. Adaptive strategies, mixed-methods research, and validated tools are needed to capture long-term impacts, especially in resource-limited contexts. Policymakers should promote low-cost, culturally relevant non-digital GBL to bridge technological gaps, and future studies should explore moderators such as socio-economic status, digital literacy, and gender.

CONCLUSION

This systematic review synthesized findings from 17 empirical studies (2018–2025) on the impact of Game-Based Learning (GBL) in mathematics education. Results consistently showed that GBL enhances cognitive skills such as conceptual understanding, problem-solving, and higher-order thinking (critical and creative), improving performance in algebra, statistics, and geometry. Digital tools like escape rooms, AR/3D environments, and gamified platforms proved particularly effective in promoting deep learning and engagement. GBL also



positively influenced affective outcomes by increasing motivation, reducing math anxiety, and fostering positive attitudes. However, most studies lacked standardized, psychometrically sound instruments for measuring affective impacts, indicating a need for stronger methodological rigor.

Contextual factors, student characteristics, game design quality, intervention duration, and teacher readiness were critical, with game design and teacher competence as key determinants. A disparity remains between digital GBL in well-resourced settings and the relevance of non-digital games in limited-resource environments, reflecting a global digital divide. Overall, GBL offers a promising approach to integrating cognitive and affective learning. Future efforts should focus on contextualized game design, comprehensive teacher training, and equitable technology access, aligning with Indonesia's *Kurikulum Merdeka* and 21st-century education goals. Further research is needed to establish standardized affective assessment tools and evaluate GBL's long-term impacts across varied contexts.

ACKNOWLEDGMENTS

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Revisiting Digital Game-Based Learning in Mathematics: Global Insights into Thinking and Attitudes from a PRISMA-Guided Review

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ABSTRACT

This study employed a Systematic Literature Review (SLR) following the PRISMA 2020 guidelines to evaluate the impact of Game-Based Learning (GBL) on students' cognitive and affective domains in mathematics education, synthesizing evidence from 17 empirical studies, published between 2018 and early 2025, were rigorously selected based on strict criteria focusing on methodological quality and relevance to cognitive and affective domains in mathematics education. The findings consistently indicate that GBL significantly improves cognitive outcomes, including conceptual understanding, problem-solving skills, and critical thinking abilities, particularly when supported by digital tools such as augmented reality, 3D escape rooms, and gamified platforms. In addition, GBL positively influences affective outcomes by increasing student motivation and fostering more favorable attitudes toward mathematics, while also reducing math anxiety. However, assessments of affective domains remain less standardized compared to those of cognitive outcomes. Key contextual factors such as students' prior knowledge, the quality of game design, intervention duration, and teacher preparedness were found to be critical in determining GBL effectiveness. The review highlights the dominance of digital GBL in resource-rich environments, while also recognizing the potential of non-digital adaptations in low-resource contexts. Drawing on diverse international evidence, this review underscores GBL's potential as an innovative pedagogical strategy that effectively integrates cognitive and affective learning. Practical recommendations include culturally responsive game design, comprehensive teacher training, and equitable access to technology to ensure successful GBL implementation across varied educational settings.

KEYWORDS

Game-Based Learning; Mathematics Education; Cognitive Domain; Affective Domain; Systematic Review

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INTRODUCTION

Mathematics education plays a fundamental role worldwide, including in low-income nations and Least Developed Countries (LDCs), where persistent challenges such as limited infrastructure, inadequate teacher competence, and restricted access to technology hinder learning. Despite its centrality in equipping students with digital literacy, adaptability to automation, and complex problem-solving skills (Szabo et al., 2020; Yulianto et al., 2024),

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1. Synthesizing Evidence on Game-Based Learning in Mathematics: A PRISMA-Guided Review
2. Revisiting Game-Based Learning in Mathematics: Effects on Thinking, Attitudes, and Equity from a Global Perspective
3. From Understanding to Enjoyment: The Dual Impact of Game-Based Learning in Mathematics Education
4. The Role of Digital Game-Based Tools in Mathematics Education: Insights from a Systematic Review
5. Gamifying Mathematics: A Systematic Review of Pedagogical Innovations and Learning Outcomes

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mathematics often evokes anxiety, low motivation, and weak learning engagement. The 2022 PISA results revealed that Indonesian students scored only 366 in mathematics, over 100 points below the OECD average of 472, highlighting not merely statistical variance but a systemic gap in mathematical literacy and higher-order thinking skills. Addressing this disparity requires more than curriculum reform; it demands pedagogical innovations that integrate both cognitive and affective dimensions. One promising approach is Game-Based Learning (GBL), which has been shown to enhance reasoning, motivation, and engagement through interactive, technology-enhanced environments, both digital and non-digital, even in contexts with limited educational support (Gundersen & Lampropoulos, 2025; Yulianto et al., 2025; Hu et al., 2022).

GBL has gained growing recognition in STEM education due to its constructivist underpinnings, capacity for real-time feedback, and effectiveness in mitigating mathematics anxiety (Moon et al., 2024; Munirah et al., 2020). Empirical studies from high-income countries such as the United States, the United Kingdom, and Spain consistently demonstrate significant improvements in cognitive performance and student engagement (Kiili et al., 2021; Clark & Picton, 2020; Jimenez et al., 2020). In contrast, research from low- and middle-income countries (LMICs), including Indonesia (Munirah et al., 2020), Malaysia (Lee & Mohd, 2023), Nigeria (Oladejo et al., 2023), and rural India (Jain et al., 2023), remains fragmented and often hindered by limited digital infrastructure, insufficient teacher preparedness, and a lack of consistent outcome metrics (Radkowsch et al., 2021). Notably, the existing body of literature is disproportionately focused on cognitive outcomes, while affective domains, such as student motivation, attitudes, and emotional engagement, remain critically underexplored. Only approximately 15% of studies utilize standardized affective assessment tools (Varas-Pavez et al., 2025). To bridge these global and contextual gaps, this review adopts the PRISMA 2020 protocol combined with a thematic synthesis approach, an underutilized method in GBL scholarship, to systematically map both cognitive and affective learning outcomes across diverse socioeconomic and educational landscapes.

To address this research gap, the present study conducts a systematic literature review (SLR) of peer-reviewed articles published between 2018 and 2025. This timeframe encompasses two pivotal shifts in mathematics education. First, 2018 marked the emergence of national digital transformation initiatives that integrated GBL into mathematics curricula in countries such as Singapore, South Korea, Finland, and the Netherlands (Mutlu-Bayraktar et al., 2019; Cai & Hwang, 2020; Schöbel et al., 2021). For instance, Singapore's EdTech

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Masterplan (2018–2023) advocated for personalized mathematics instruction through digital games (Kim & Pang, 2022), while Finland revised its curriculum to support exploratory and digitally mediated mathematical learning (Lerkkanen et al., 2023). Second, the COVID-19 pandemic (2020–2022) catalyzed the expansion of remote learning and intensified the demand for emotionally engaging digital pedagogies. This development rendered GBL frameworks increasingly relevant for addressing both cognitive and affective learning outcomes (Lee & Mohd, 2023). Extending the review through 2025 allows for the inclusion of post-pandemic innovations and recent empirical insights in mathematics education. This study offers a distinctive contribution by systematically integrating cognitive domains (e.g., reasoning, problem-solving) and affective dimensions (e.g., motivation, attitude) within the context of GBL, an intersection rarely addressed in prior reviews. In doing so, it provides both theoretical grounding and practical implications for the design of emotionally responsive GBL environments (Szabo et al., 2020; PISA, 2023).

This review focuses on the period from 2018 to 2025, a pivotal era in educational innovation marked by the global acceleration of game-based learning (GBL) research and implementation. Foundational studies and national initiatives such as Singapore’s EdTech Masterplan (2018–2023) and Finland’s 2018 curriculum reforms, which emphasized playful and technology-integrated mathematics instruction, signaled an early shift toward digital game-based approaches even before the COVID-19 pandemic (Mutlu-Bayraktar et al., 2019; Cai & Hwang, 2020; Schöbel et al., 2021). These developments laid a critical foundation for the rapid expansion of GBL during the pandemic (2020–2022), as remote and hybrid learning modes became widespread (Lee & Mohd, 2023). Employing the PRISMA 2020 guidelines (Page et al., 2021) and thematic synthesis methodology (Thomas & Harden, 2008), this review addresses significant methodological limitations in prior GBL literature reviews (Radkowsch et al., 2021). Specifically, it aims to: (1) analyze the cognitive outcomes associated with GBL; (2) examine its effects on affective learning dimensions; (3) identify prevailing implementation patterns; and (4) investigate contextual moderators influencing GBL effectiveness across varied educational contexts.

METHODS

GBL in mathematics has garnered significant attention for its potential to enhance both cognitive and affective learning outcomes. This study systematically reviews existing research to examine the impact of GBL in secondary education, outlining the type of review

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Review Type and Objectives

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Data Sources and Search Strategy

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Inclusion and Exclusion Criteria

Inclusion criteria encompassed empirical studies on Digital Game-Based Learning (GBL) in mathematics education involving secondary school students, reporting cognitive and/or affective outcomes with clearly defined indicators, employing experimental or quasi-experimental designs with group comparisons, and published in peer-reviewed English-language journals. Exclusion criteria included studies focusing on non-digital games, special populations (e.g., students with disabilities or gifted students), theoretical articles, reviews, editorials, book chapters, conference papers, and studies lacking full-text access or reporting only indirect outcomes (e.g., motivation without academic performance data).

Screening and Selection Process

A four-stage PRISMA flow was followed: *identification*, *screening*, *eligibility*, and *inclusion*. The initial search yielded 16.315 records. After removing duplicates, 826 articles remained for title and abstract screening. Based on relevance and inclusion criteria, 257 articles proceeded to full-text assessment. Of these, 17 studies met all inclusion criteria and were retained for final synthesis. The screening process followed guidelines adapted from Lo et al. (2024) and is illustrated in Figure 2.

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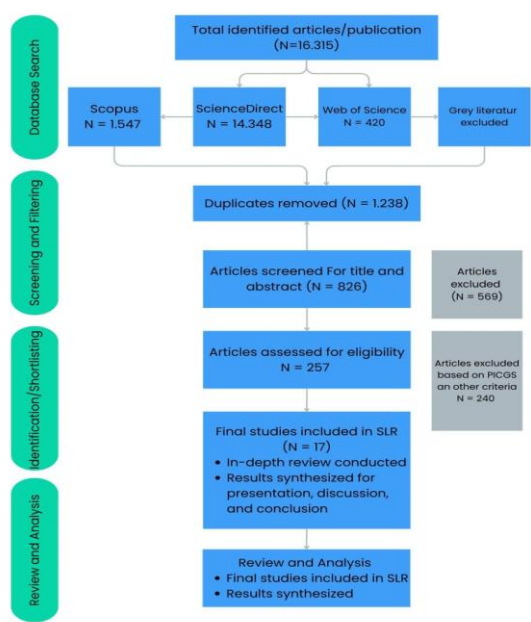


Figure 2. PRISMA flow diagram



Quality Appraisal

The methodological quality of the selected studies was assessed using the Critical Appraisal Skills Programme (CASP) checklist (CASP, 2018), a validated tool for evaluating the credibility, relevance, and rigor of qualitative and quantitative research. This structured appraisal ensured consistent judgments on research clarity, validity, and applicability. Only studies scoring $\geq 70\%$ on the CASP scale were included in the synthesis. To reduce potential publication and selection bias, a comprehensive multi-database search and a rigorous multi-stage screening were conducted. Given the qualitative synthesis, funnel plot analysis was not applicable. Two independent reviewers appraised all studies, resolving discrepancies through discussion to ensure objectivity.

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Data Extraction and Synthesis

This review adhered to the PRISMA 2020 guidelines (Page et al., 2021) to ensure methodological transparency and replicability. A structured coding matrix developed in Excel was used to systematically capture key study attributes, including authorship, year, country, research design, participants, type of intervention, outcomes, instruments, and major findings. Data were analyzed thematically through both inductive and deductive approaches (Thomas & Harden, 2008). Cognitive and affective learning outcomes were established as initial thematic categories, which were subsequently refined into subthemes such as reasoning, learner engagement, and anxiety reduction through open coding.

Three coders were involved in the data extraction and thematic analysis process: two internal (members of the author team) and one external (an independent reviewer). Each coder conducted the analysis independently using a shared coding framework. Discrepancies were addressed through consensus meetings involving all coders until full agreement was achieved. All consensus meetings were systematically documented to enhance procedural transparency and minimize bias. The inter-rater reliability was substantial ($\kappa = 0.81$; Landis & Koch, 1977), underscoring the robustness and consistency of the coding process. To enhance analytical depth and contextual accuracy, a triangulated coding strategy was employed. The studies were classified according to educational level, type of game-based learning (digital, non-digital, or gamified), and geographical context (developed vs. developing countries) to identify potential subgroup patterns. Due to the methodological heterogeneity of the included studies, a meta-analysis was not appropriate. Instead, findings were synthesized using descriptive statistics and narrative synthesis. Thematic validity was further supported through peer debriefing.

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Table 2 presents a summary of the 17 included studies, organized by methodological characteristics and geographic distribution. Table 1 presents the 17 included studies, summarizing their methodological diversity and geographical distribution.

Table 1. Overview of Selected Studies on Game-Based Learning in Mathematics Education

No	Author(s)	Year	Country	Method	Article Title
1	Kiili et al.	2018	Germany	Experimental	Evaluating the effectiveness of a game-based rational number training – in-game metrics as a learning indicator
2	Groening & Binnewies	2019	Germany	Experimental (between-subjects)	Achievement unlocked! – The impact of digital achievements as a gamification element on motivation and performance.
3	Wardani et al.	2019	Indonesia	Quasi-experimental	Evaluation of an educational media on cube nets based on learning effectiveness and gamification parameters
4	Abidin et al.	2019	Malaysia	Quasi-experimental	A research of gamification impact in learning mathematics
5	Barros et al.	2020	Portugal	Experimental	The effect of the serious game template on learning arithmetic polynomial operations
6	Jimenez et al.	2020	Spain	Quasi-experimental	Digital Escape Room, Using Genial.ly and A Breakout to Learn Algebra at the Secondary Educational Level in Spain
7	Legaki et al.	2020	Greece	Experimental (between-subjects)	The effect of challenge-based gamification on learning: An experiment in the context of statistics education
8	Yung et al.	2020	Hong Kong	Experimental	1 Slash 100%: Gamification of mathematics with a hybrid QR-based card game
9	Leonardou et al.	2020	Greece	Experimental	Techniques to motivate learner improvement in game-based assessment
10	Rosillo & Montes	2021	Spain	Quasi-experimental	An escape room dual-mode approach to teach maths during the COVID-19 era
11	Chiu & Seah	2024	Singapore	Quasi-experimental	Values and valuing pedagogies in effect focus mathematics teaching
12	Bayaga	2024	South Africa	Experimental	Enhancing mathematics problem-solving skills in an AI-driven environment: Integrated SEM-neural network approach
13	Zapata et al.	2024	Colombia	Quasi-experimental	Enhancing mathematics learning with a 3D augmented reality escape room
14	Christopoulos et al.	2024	Greece	Experimental	Is Immersion in 3D virtual games associated with mathematical Ability Improvement in Game-based Learning?
15	Ding & Yu	2024	Taiwan	Experimental (between-subjects)	Serious game-based learning and learning by making games: Types of game-based pedagogies and student gaming hours impact students' science learning outcomes
16	Choi et al.	2025	South Korea	Quasi-experimental	Stalemate? The complex relationship between educational chess and students' skills
17	Gui et al.	2025	China	Experimental (between-subjects)	Dadys composed of members with high prior knowledge are most conducive to digital game-based collaborative learning



RESULT AND DISCUSSION

This section presents synthesized findings from a systematic review of GBL in mathematics education, emphasizing trends, methodologies, educational contexts, and regional patterns. The analysis identifies core themes, contextual variations, and gaps that shape current practices and inform future research directions.

Results Contextual Mapping of Selected Studies

This review synthesizes 17 peer-reviewed articles selected from Scopus, Web of Science, and ScienceDirect based on methodological rigor and relevance. The journals were ranked using Scimago Journal Rank (SJR) and Journal Impact Factor (JIF), resulting in 13 Q1, 2 Q2, and 2 Q4 publications, indicating strong academic credibility. Studies were analyzed across four dimensions: geography, publication year, research method, and educational level. The research spans 13 countries, with major contributions from Southern and Western Europe particularly Greece (Christopoulos et al., 2024; Legaki et al., 2020; Leonardou et al., 2020), Germany (Groening & Binnewies, 2019; Kiili et al., 2018), Portugal (Barros et al., 2020), and Spain (Jiménez et al., 2020; Rosillo & Montes, 2021) as well as Asia (Hong Kong: Yung et al., 2020; Singapore: Chiu & Seah, 2024; Taiwan: Ding & Yu, 2024; South Korea: Choi et al., 2025; China: Gui et al., 2025), and the Global South (Indonesia: Wardani et al., 2019; Malaysia: Abidin et al., 2019; South Africa: Bayaga, 2024; Colombia: Zapata et al., 2024).

The global landscape of GBL research highlights both its widespread pedagogical potential and the persistent structural inequities between the Global North and Global South. Studies originating from countries such as Indonesia, Malaysia, and Nigeria consistently identify critical barriers, including inadequate infrastructure, limited teacher capacity, high internet costs, and fragmented policy frameworks, that impede the scalable adoption of GBL initiatives (COL, 2020; Cueto et al., 2023). In stark contrast, high-income nations like Finland, the United Kingdom, and the United States report successful GBL integration, underpinned by advanced game design, well-established digital ecosystems, and robust educational infrastructures (Choi et al., 2025; Zapata et al., 2024). These disparities underscore the risks of uncritically transplanting pedagogical models from the Global North, which may neglect local epistemologies and socio-technical conditions, a dynamic increasingly critiqued as a form of digital colonialism. Cueto et al. (2023) warn against universalist approaches, instead advocating for context-sensitive, participatory, and culturally grounded GBL frameworks. Consequently, effective implementation of GBL in the Global

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South must address not only issues of access and technical feasibility but also embrace epistemological diversity and contextual relevance to ensure equitable, sustainable educational outcomes.

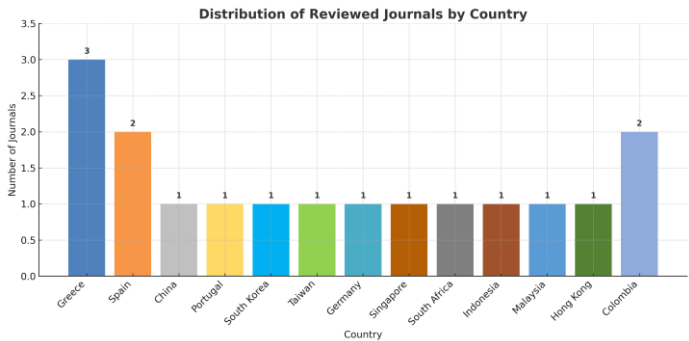


Figure 3. Distribution of Articles by Region

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Publication Trends and Game Types in Reviewed Studies

As illustrated in Figure 4, the 17 reviewed studies span the period from 2018 to 2025, reflecting dynamic and fluctuating publication trends. Initial contributions emerged between 2018 and 2020 (e.g., Kiili et al., 2018; Abidin et al., 2019; Barros et al., 2020), indicating a growing scholarly interest in game-based learning (GBL) within mathematics education. However, a significant decline was observed between 2021 and 2023, during which only a single study was published (Rosillo & Montes, 2021). This lull was followed by a notable resurgence in 2024–2025 (e.g., Christopoulos et al., 2024; Gui et al., 2025), suggesting renewed academic attention in the post-pandemic context. Across the corpus, GBL was consistently associated with improved cognitive outcomes, particularly in mathematical problem-solving and reasoning (e.g., Kiili et al., 2018; Barros et al., 2020). In parallel, gamification approaches were shown to significantly enhance student motivation and affective engagement (Groening & Binnewies, 2019).

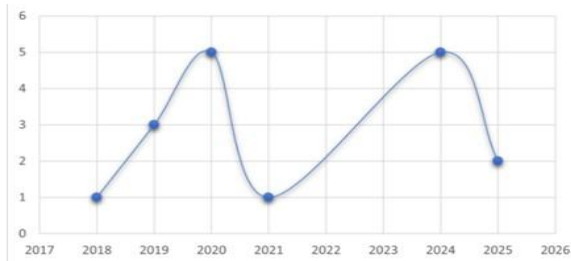


Figure 4. Distribution of Articles by Year



Figure 5 categorizes the GBL approaches into three distinct types: (1) Digital GBL, which predominates in 11 studies (e.g., Kiili et al., 2018; Christopoulos et al., 2024); (2) Digital Gamification, featured in four studies (e.g., Gui et al., 2025); and (3) Non-Digital GBL, identified in two studies (Bayaga, 2024; Choi et al., 2025). This distribution underscores the dominance of digital GBL, likely due to its adaptability, interactive features, and alignment with contemporary pedagogical frameworks and technology-enhanced learning environments.

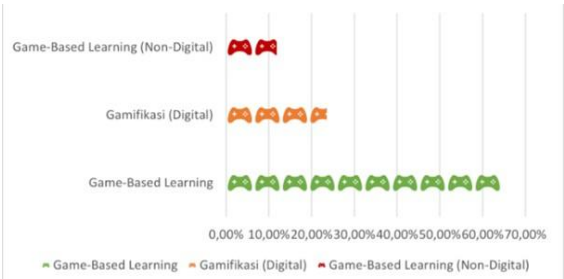


Figure 5. Distribution of Articles by Game Type

Research Design and Educational Context Distribution

As illustrated in Figure 6, the reviewed studies employed three primary research designs: true experimental (7 studies), between-subjects experimental (4 studies), and quasi-experimental (7 studies). True experimental designs characterized by random group assignment and controlled interventions were utilized in studies by Kiili et al. (2018), Barros et al. (2020), Bayaga et al. (2024), Yung et al. (2020), Leonardou et al. (2020), and Christopoulos et al. (2024). Non-randomized between-subjects designs were adopted by Gui et al. (2025), Ding and Yu (2024), Groening and Binnewies (2019), and Legaki et al. (2020). Quasi-experimental designs, which involve comparison groups without randomization, were employed in studies by Jimenez et al. (2020), Choi et al. (2025), Chiu and Seah (2024), Wardani et al. (2019), Abidin et al. (2019), Rosillo and Montes (2021), and Zapata et al. (2024).

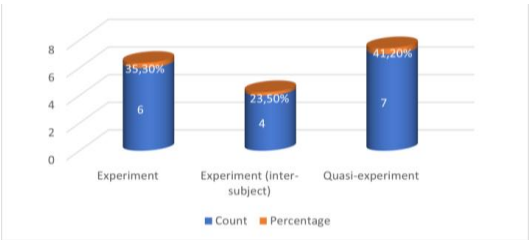


Figure 6. Distribution of articles based on research methods



As shown in Figure 7, GBL studies were distributed across three educational levels: elementary/lower secondary (4 studies; e.g., Kiili et al., 2018; Choi et al., 2025), junior secondary (4 studies; e.g., Wardani et al., 2019; Barros et al., 2020), and combined junior–senior secondary (9 studies; e.g., Bayaga, 2024; Yung et al., 2020). This distribution reflects both methodological diversity and the broad applicability of game-based learning (GBL) across different age groups in mathematics education.

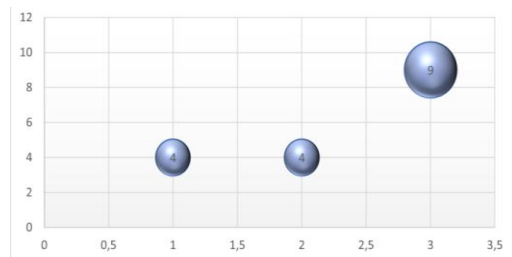


Figure 7. Distribution of articles based on education level

Thematic Trends in Game-Based Learning Research in Mathematics Education

A review of 17 studies revealed nine key GBL themes in mathematics: problem-solving, motivation, general mathematics, algebra, basic skills, rational numbers, polynomial operations, statistics, and cube nets (Figure 8). Long-term interventions (6–12 weeks, 2–3 sessions/week, @60–90 minutes) demonstrated sustained improvements in conceptual understanding, self-efficacy, and learning persistence. For example, Zapata et al. (2024, Colombia: 12 weeks, 3 sessions/week, @75 minutes) and Gui et al. (2025, China: 8 weeks, 2 sessions/week, @60 minutes). In contrast, short-term formats (1–2 weeks, ≤4 sessions, @60–90 minutes) primarily enhanced attention and emotional engagement but had limited cognitive impact. For instance, Groening & Binnewies (2019, Germany: 1 week, 2 sessions, @60 minutes), Kiili et al. (2018, Finland: 2 weeks, 4 sessions, @90 minutes), and Abidin et al. (2019, Malaysia: 1 week, 2 sessions, @60 minutes).

Problem-solving and learning motivation were the most frequently studied themes. Examples include Bayaga (2024, South Africa: 8 weeks, 2 sessions/week, @60 minutes), Christopoulos et al. (2024, Greece: 10 weeks, 3 sessions/week, @90 minutes), Ding & Yu (2024, China: 6 weeks, 2 sessions/week, @60 minutes), Groening & Binnewies (2019, Germany: 1 week, 2 sessions, @60 minutes), Gui et al. (2025, China: 8 weeks, 2 sessions/week, @60 minutes), and Legaki et al. (2020, Greece: 6 weeks, 2 sessions/week, @60 minutes). General mathematics was examined by Abidin et al. (2019, Malaysia: 1 week, 2 sessions, @60 minutes), Chiu & Seah (2024, Singapore: 6 weeks, 2 sessions/week, @75

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minutes), and Zapata et al. (2024, Colombia: 12 weeks, 3 sessions/week, @75 minutes). Algebra was studied by Jiménez et al. (2020, Spain: 8 weeks, 2 sessions/week, @60 minutes) and Rosillo & Montes (2021, Mexico: 6 weeks, 2 sessions/week, @75 minutes). Basic skills were explored by Leonardou et al. (2020, Greece: 4 weeks, 2 sessions/week, @60 minutes) and Yung et al. (2020, Hong Kong: 3 weeks, 3 sessions/week, @60 minutes). Rarely studied topics included rational numbers (Kiili et al., 2018, Finland: 2 weeks, 4 sessions, @90 minutes), polynomial operations (Barros et al., 2020, Brazil: 5 weeks, 2 sessions/week, @60 minutes), statistics (Legaki et al., 2020, Greece: 6 weeks, 2 sessions/week, @60 minutes), and spatial geometry (Wardani et al., 2019, Indonesia: 4 weeks, 2 sessions/week, @75 minutes).

Although GBL has proven effective in enhancing learning motivation, its impact on higher-order thinking remains uneven, particularly in short-term implementations or resource-limited contexts, where success heavily depends on infrastructure, teacher preparedness, and sociocultural perceptions of technology (Ding & Yu, 2024; Gui et al., 2025). Furthermore, the lack of standardized affective instruments (Radkowsitch et al., 2021) limits the validity of affective evaluations, highlighting the need for broader thematic coverage and stronger methodological tools in future GBL studies.

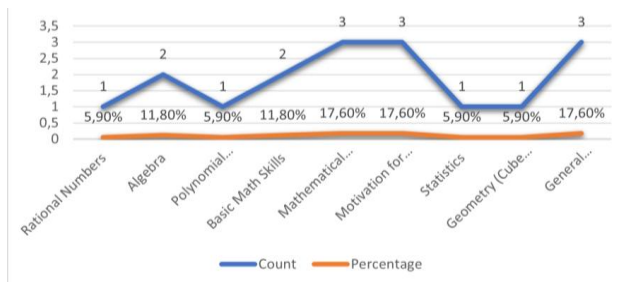


Figure 8 presents the distribution of articles based on their respective research topics.

Discussion

This section discusses the impact of GBL on students' cognitive and affective domains in mathematics, including key influencing factors and theoretical perspectives drawn from 17 reviewed studies.

The Impact of GBL on Students' Cognitive Domain in Mathematics Education.

Analysis of 17 reviewed studies consistently indicates that Game-Based Learning (GBL) significantly enhances students' cognitive abilities in mathematics, notably in conceptual understanding, problem-solving, and higher-order thinking (Kiili et al., 2018; Jimenez et al., 2020; Barros et al., 2020). Digital games such as Escape Room and Tempoly

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improved algebraic reasoning and engagement, while GBL was particularly effective for students with strong prior knowledge in collaborative contexts (Gui et al., 2025). AI-driven platforms also boosted cognitive performance (Bayaga et al., 2024). Geometry and 3D topics benefited from visual-rich, AR-supported instruction (Wardani et al., 2019; Zapata et al., 2024), and hybrid models showed positive post-test results across diverse pedagogies (Rosillo & Montes, 2021; Yung et al., 2020).

Pedagogically, game-based tasks in statistics (Legaki et al., 2020) and gamified reward systems (Leonardou et al., 2020), reinforced by immersive 3D tools (Christopoulos et al., 2024), align with Constructivist Learning Theory (Piaget, 1972; Vygotsky, 1978) by promoting active, meaningful learning. They also reflect Cognitive Load Theory (Sweller, 1988; Mayer, 2005), as multimodal designs reduce extraneous load, enhancing spatial understanding. Nonetheless, contextual disparities such as digital access, teacher readiness, and cultural perceptions affect GBL’s effectiveness, especially in under-resourced settings. For instance, Wardani et al. (2019) and Ding & Yu (2024) observed diminished student engagement and AR implementation due to infrastructure gaps and insufficient institutional support. These findings emphasize the necessity of systemic preparedness to ensure equitable and effective GBL adoption.

The Impact of GBL on Students’ Affective Domain in Mathematics Education.

Game-Based Learning (GBL) has shown significant positive effects on students’ affective domains, boosting motivation, emotional engagement, and positive attitudes, while reducing math anxiety across seven of the 17 reviewed studies. These outcomes are in line with Self-Determination Theory (Ryan & Deci, 2020), which emphasizes autonomy, competence, and relatedness as key drivers of intrinsic motivation. Mechanisms such as positive feedback, rewards, and challenge-based gameplay (Jiménez et al., 2020; Leonardou et al., 2019) effectively supported these needs. Jiménez et al. (2020), for instance, found that Digital Escape Rooms improved both algebra performance and motivation. Likewise, gamification tools like badges and leaderboards enhanced engagement and confidence (Groening & Binnewies, 2019), while feedback strategies redefined math as enjoyable and stimulating (Leonardou et al., 2019). Choi et al. (2025) reported increased participation and competitive spirit through non-digital chess-based GBL. Immersive AR and dual-mode escape rooms further elevated students’ interest and comfort (Rosillo & Montes, 2021; Zapata et al., 2024).

However, limitations remain. Some studies (Ding & Yu, 2024; Leonardou et al., 2020)

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minimally addressed affective outcomes and lacked standardized instruments, restricting generalizability. Variations in intervention duration, task complexity, and contextual relevance likely contributed to inconsistent findings. Although GBL trends toward enhancing motivation and lowering anxiety, over-reliance on self-reports introduces potential bias. Future research should incorporate multi-method affective assessments, including behavioral and physiological measures, to ensure a more valid and robust evaluation.

Key Themes in the Implementation of GBL

This systematic review synthesizes four major themes that integrate cognitive, affective, and contextual dimensions of GBL in mathematics education, an integrative lens that remains underexplored in the existing literature.

1. **Prevalence of Digital Platforms:** Ten out of seventeen studies employed digital technologies such as escape rooms (Jiménez et al., 2020; Zapata et al., 2024), 3D virtual environments (Christopoulos et al., 2024), gamification systems (Leonardou et al., 2020), and AR/AI-based simulations (Bayaga, 2024; Yung et al., 2020). These tools enhance interactivity, real-time feedback, and learner autonomy capabilities aligned with 21st-century competencies, including critical thinking, creativity, and digital literacy.
2. **Emphasis on Problem-Solving and Higher-Order Thinking:** Nine studies emphasized GBL’s potential to foster analytical reasoning and deep conceptual understanding, particularly among upper-secondary students, through interactive and problem-based mathematical tasks (Barros et al., 2020; Gui et al., 2025).
3. **Enhancement of Motivation and Engagement:** Seven studies documented increased intrinsic motivation, emotional involvement, and positive attitudes toward mathematics, attributed to gamified elements such as reward systems, immediate feedback, and collaborative gameplay (Choi et al., 2025; Groening & Binnewies, 2019; Jiménez et al., 2020).
4. **Global Implementation and Contextual Flexibility:** GBL was implemented across diverse geographical contexts, including Europe, Asia, Africa, and Latin America, demonstrating its adaptability to varying curricular frameworks, technological infrastructures, and cultural norms (Rosillo & Montes, 2021; Zapata et al., 2024).

Despite these promising findings, the majority of interventions were short-term, ranging from a single session to 3–4 weeks, which, although effective for immediate engagement, showed limited persistence in cultivating long-term reasoning and critical thinking (e.g., Jiménez et al., 2020; Leonardou et al., 2020). Moreover, only a few studies employed delayed

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post-tests, leaving the long-term cognitive and affective outcomes of GBL largely unexamined. This gap underscores the urgent need for longitudinal research to assess the sustained impact of GBL in mathematics learning.

Contextual Factors Influencing the Effectiveness of GBL

The effectiveness of GBL in mathematics depends not only on game types but also on contextual factors identified across 17 reviewed studies: student characteristics, game design, intervention duration, and teacher readiness.

1. **Student Characteristics** Learners with stronger prior knowledge and metacognitive skills show greater GBL gains, particularly in collaborative contexts (Gui et al., 2025), aligning with Constructivist Learning Theory. This suggests the need to adapt GBL to students' readiness levels.
2. **Game Type and Design** Game format influences outcomes: AR and 3D simulations enhance conceptual understanding (Kiili et al., 2018; Zapata et al., 2024); gamification elements like points and badges boost motivation in routine tasks (Groening & Binnewies, 2019); non-digital games (e.g., chess) promote critical thinking in low-tech settings (Choi et al., 2025). Thus, game choice must align with learner needs and technological context (Zapata et al., 2024).
3. **Duration of Intervention** Short-term GBL boosts motivation but has fleeting effects (Leonardou et al., 2020). Sustained, repeated exposure leads to more durable gains in cognition and problem-solving (Gui et al., 2025; Zapata et al., 2024). However, inconsistent duration reporting across studies hampers comparative analysis.
4. **Teacher Readiness and Infrastructure** Teacher competence and digital literacy are critical. Barriers include limited training, inadequate infrastructure, and insufficient institutional support (Wardani et al., 2019; Ding & Yu, 2024). Effective GBL requires comprehensive support systems and policy alignment.

While GBL demonstrates strong potential to enhance both cognitive and affective outcomes, its success hinges on these interrelated factors. This review, though broad in scope, has limitations. Reliance on narrative synthesis precludes effect size estimation. Variations in study design, sample sizes, and inconsistent methodological rigor limit generalizability. Exclusion of gray and non-English literature may also bias findings. Moreover, overdependence on self-report tools for affective outcomes raises concerns of subjectivity and social desirability bias.

Future research should prioritize longitudinal, mixed-methods studies incorporating

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behavioral, physiological, and performance-based measures. Investigating GBL's long-term effects, domain transferability, and the roles of moderators such as socio-economic background, gender, and digital access is essential. Additionally, scalable, low-tech GBL alternatives should be explored to ensure equity in under-resourced settings. These steps will strengthen evidence and inform more inclusive GBL integration aligned with global education goals.

CONCLUSION

This systematic review examined 17 empirical studies (2018–2025) and successfully addressed the four research objectives outlined in the introduction. First, the studies demonstrated that *Game-Based Learning* (GBL) significantly enhances students' cognitive competencies, particularly in conceptual understanding, problem-solving, and higher-order thinking, especially in topics such as algebra, statistics, and geometry. Second, in terms of affective outcomes, GBL was found to have a positive impact by increasing students' motivation, reducing math anxiety, and fostering more favorable attitudes toward learning. Third, the most prominent patterns of GBL implementation included the use of escape rooms, augmented reality (AR), and 3D gamified environments characterized by collaborative and participatory learning experiences. Fourth, the effectiveness of GBL was shown to be strongly influenced by contextual factors, such as the quality of game design, teacher readiness, and the availability of digital infrastructure.

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Systematic Review on the Impact of Game-Based Learning on Students' Cognitive and Affective Domains

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ABSTRACT

This study employed a Systematic Literature Review (SLR) following the PRISMA 2020 guidelines to evaluate the impact of Game-Based Learning (GBL) on students' cognitive and affective domains in mathematics education, synthesizing evidence from 17 empirical studies published between 2018 and 2025. The findings consistently indicate that GBL significantly improves cognitive outcomes, including conceptual understanding, problem-solving skills, and critical thinking abilities, particularly when supported by digital tools such as augmented reality, 3D escape rooms, and gamified platforms. In addition, GBL positively influences affective outcomes by increasing student motivation and fostering more favorable attitudes toward mathematics, while also reducing math anxiety. However, assessments of affective domains remain less standardized compared to those of cognitive outcomes. Key contextual factors such as students' prior knowledge, the quality of game design, intervention duration, and teacher preparedness were found to be critical in determining GBL effectiveness. The review highlights the dominance of digital GBL in resource-rich environments, while also recognizing the potential of non-digital adaptations in low-resource contexts. Drawing on diverse international evidence, this review underscores GBL's potential as an innovative pedagogical strategy that effectively integrates cognitive and affective learning. Practical recommendations include culturally responsive game design, comprehensive teacher training, and equitable access to technology to ensure successful GBL implementation across varied educational settings.

KEYWORDS

Game-Based Learning; Mathematics Education; Cognitive Domain; Affective Domain; Systematic Review

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INTRODUCTION

Mathematics education, both in developed and developing countries like Indonesia, is fundamental in preparing learners for the demands of the 21st century marked by digitalization, automation, and complex problem-solving (Szabo et al., 2020; Yulianto et al., 2024). However, despite its importance, mathematics often triggers anxiety and disengagement, leading to low achievement worldwide, especially in developing regions where PISA and TIMSS scores remain below the OECD average (OECD, 2023; Kelly et al., 2020; IEA, 2020). These challenges call for pedagogical innovation beyond curriculum reform, emphasizing cognitive and affective integration. Effective learning requires student-centered strategies that build reasoning, conceptual fluency, and motivation (Bloom et al., 1956; Kunani et al., 2025). In response, Game-Based Learning (GBL) has gained prominence as an approach that enhances problem-solving, reasoning, and student engagement through



interactive, technology-enhanced platforms such as digital simulations, puzzles, and gamified assessments (Hu et al., 2022; Gundersen & Lampropoulos, 2025).

GBL has gained widespread attention in STEM education for its constructivist approach, real-time feedback, and ability to reduce mathematics anxiety (Moon et al., 2024; Munirah et al., 2020). While promising results are evident in high-income countries, findings from developing regions remain fragmented, complicated by varied game types, digital simulations, board games, and inconsistent research designs and outcome measures (Radkowsitch et al., 2021). Prior studies have largely emphasized cognitive outcomes, with limited focus on affective domains crucial for sustaining motivation and learning success (Varas-Pavez et al., 2025). Moreover, only 15% of GBL research employs standardized tools for affective assessment (Radkowsitch et al., 2021), and few explore its role in shaping emotional engagement or attitudes in mathematics learning (Lee Yan & Mohd Matore, 2023). Addressing these gaps, this review adopts PRISMA 2020 guidelines and thematic synthesis, rarely been applied in prior mathematics GBL reviews to comprehensively map cognitive and affective impacts across diverse contexts.

To address this gap, this study conducts a systematic literature review (SLR) of peer-reviewed articles published between 2018 and 2025, focusing on both cognitive (problem-solving, reasoning, conceptual understanding) and affective (motivation, attitude, engagement) outcomes of GBL in mathematics education dimensions rarely integrated in previous reviews. This dual focus offers theoretical and practical insights for developing evidence-based, emotionally responsive GBL frameworks, which are increasingly critical in the post-pandemic era marked by rapid digital and remote learning expansion (Szabo et al., 2020; OECD, 2023).

The 2018–2025 timeframe captures the acceleration of educational technologies and GBL adoption triggered by COVID-19, underscoring the need for a comprehensive synthesis to guide hybrid and virtual teaching models. Moreover, this review advances prior studies by rigorously applying PRISMA 2020 guidelines and thematic synthesis, ensuring methodological transparency and replicability elements often lacking in earlier GBL-focused SLRs (Radkowsitch et al., 2021). Specifically, this study aims to: (1) assess GBL's impact on students' cognitive development; (2) evaluate its influence on affective domains; (3) identify key GBL implementation themes; and (4) explore contextual factors moderating GBL effectiveness.



METHODS

Review Type and Objectives

This study employed a systematic literature review (SLR) guided by the PRISMA 2020 protocol (Page et al., 2021), aiming to synthesize empirical evidence on the effects of Digital Game-Based Learning (DGBL) on students' cognitive (conceptual understanding, reasoning, problem-solving, critical and creative thinking) and affective outcomes (motivation, engagement, attitudes) in primary and secondary mathematics education. The review period of 2018–2025 was chosen to capture recent advancements in digital Game-Based Learning (DGBL), especially given the surge in technology adoption during and after the COVID-19 pandemic, which has significantly transformed educational practices globally.

Data Sources and Search Strategy

The literature search was conducted in Scopus, Web of Science (WoS), and ScienceDirect using Boolean operators (“AND”, “OR”) with the terms: “game-based learning” OR “gamification” AND “mathematics” OR “mathematics education” AND “cognitive domain” OR “affective domain”. The search was limited to peer-reviewed English journal articles, published between January 2018 and May 2025, available in full-text Open Access. A pilot search was first carried out to refine keywords and Boolean strings for relevance and retrieval quality. Citation tracking and grey literature were excluded to maintain methodological rigor and reduce publication bias. Figure 1 illustrates the distribution of the term “math gamification” in the Scopus database.

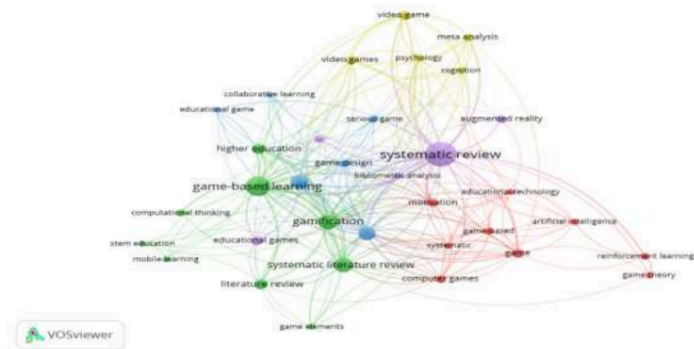


Figure 1. Distribution of the Term “Math Gamification” Based on Scopus Database Retrieval



Inclusion and Exclusion Criteria

Inclusion and exclusion criteria were established to ensure the relevance and methodological rigor of this systematic review. Included studies were empirical, focused on Digital Game-Based Learning (DGBL) in mathematics education, involved primary or secondary students, measured cognitive and/or affective outcomes using clear indicators, applied experimental or quasi-experimental designs with group comparisons, and were peer-reviewed English journal articles. Excluded studies were those involving non-digital games, special populations (e.g., students with disabilities or gifted learners) to reduce bias, as well as theoretical articles, literature reviews, editorials, book chapters, and conference papers. Additionally, studies reporting only indirect outcomes (e.g., motivation without academic performance data) or lacking full-text availability were omitted.

Screening and Selection Process

A four-stage PRISMA flow was followed: *identification*, *screening*, *eligibility*, and *inclusion*. The initial search yielded 16,315 records. After removing duplicates, 826 articles remained for title and abstract screening. Based on relevance and inclusion criteria, 257 articles proceeded to full-text assessment. Of these, 17 studies met all inclusion criteria and were retained for final synthesis. The screening process followed guidelines adapted from Margot & Kettler (2019), Mohamed Shaffril et al. (2021) and is illustrated in Figure 1.

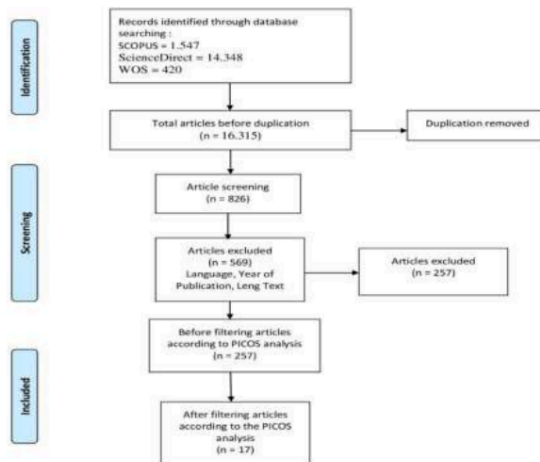


Figure 2. PRISMA flow diagram



Quality Appraisal

The quality of the included studies was evaluated using the CASP checklist to ensure methodological rigor, design clarity, and outcome reliability. Only studies scoring $\geq 70\%$ were included. Potential biases, such as publication and selection bias, were minimized through comprehensive database searches and multi-stage screening. Formal funnel plot analysis was omitted due to the qualitative synthesis. Two independent reviewers conducted the appraisal, resolving discrepancies through consensus to maintain objectivity.

Data Extraction and Synthesis

This review adhered to PRISMA 2020 guidelines (Page et al., 2021) to ensure transparency and replicability. A structured coding matrix in Excel captured essential study details: authors, year, country, method, participants, intervention type, cognitive and affective outcomes, instruments, and main results. Thematic synthesis combined inductive and deductive approaches; predefined themes (cognitive vs. affective) were expanded via open coding into subthemes like reasoning, engagement, and anxiety reduction. Studies were categorized by education level, game type (digital, non-digital, gamification), and regional context (developed vs. developing), enabling pattern comparison. Two independent reviewers conducted data extraction and coding; discrepancies were resolved by consensus. Cohen's Kappa (0.81) confirmed substantial inter-rater reliability. Due to methodological heterogeneity, meta-analysis was not performed; instead, descriptive statistics and narrative synthesis summarized findings and gaps. Themes were validated through peer debriefing to ensure trustworthiness. Table 2 summarizes the 17 included studies, highlighting intervention diversity and geographical distribution.

Table 2. Overview of Selected Studies on Game-Based Learning in Mathematics Education

Author(s)	Year	Country	Study Design	Game Type / Approach	Learning Focus	Outcomes Measured
Kiili et al.	2018	Germany	Experimental	Digital Rational Number Game	Fractions and Rational Number Concepts	Problem-solving, Engagement
Groening & Binnewies	2019	Germany	Between-Subjects	Gamification (Digital Rewards)	Motivation and Academic Performance	Motivation, Performance
Wardani et al.	2019	Indonesia	Quasi-Experimental	Digital Media + Gamified Tasks	3D Geometry (Cube Nets)	Achievement, Student Motivation
Abidin et al.	2019	Malaysia	Quasi-Experimental	Points & Badges Gamification	General Mathematics Concepts	Engagement, Performance
Barros et al.	2020	Portugal	Experimental	Serious Game	Polynomial	Conceptual



Author(s)	Year	Country	Study Design	Game Type / Approach	Learning Focus	Outcomes Measured
				(Tempoly)	Operations	Understanding, Accuracy
Jiménez et al.	2020	Spain	Quasi-Experimental	Digital Escape Room	Algebra Learning	Motivation, Collaboration, Problem-solving
Legaki et al.	2020	Greece	Between-Subjects	Challenge-Based Gamification	Statistical Literacy	Achievement, Cognitive Load
Yung et al.	2020	Hong Kong	Experimental	Hybrid Card & QR Game	Percentages and Fractions	Engagement, Performance
Leonardou et al.	2020	Greece	Experimental	Game-Based Assessment Tools	Learner Motivation Strategies	Engagement, Improvement Tracking
Rosillo & Montes	2021	Spain	Quasi-Experimental	Dual-Mode Escape Room	Remote Algebra Instruction	Cognitive Engagement, Motivation
Chiu & Seah	2024	Singapore	Quasi-Experimental	Contextual Gamified Tasks	Values-Based Math Teaching	Affective Dispositions, Value Alignment
Bayaga	2024	South Africa	Experimental	AI-Driven Learning Environment	Problem-Solving in Math Contexts	Reasoning, Achievement, Neural Network Performance Metrics
Zapata et al.	2024	Colombia	Quasi-Experimental	3D Augmented Reality Game	Geometry Learning via Immersion	Conceptual Understanding, Student Interest
Christopoulos et al.	2024	Greece	Experimental	3D Virtual Immersive Game	Math Skill Improvement	Spatial Reasoning, Motivation
Ding & Yu	2024	Taiwan	Between-Subjects	Serious Games vs. Game Design	Science/Math Learning vs. Game Creation	Learning Gains, Gaming Duration, Interest
Choi et al.	2025	South Korea	Quasi-Experimental	Chess-Based Educational Game	Strategic Thinking in Math	Critical Thinking, Game-Driven Reasoning
Gui et al.	2025	China	Between-Subjects	Team-Based Collaborative Game	Group Learning in Math	Group Dynamics, Collaboration, Prior Knowledge Moderation

RESULT AND DISCUSSION

Results Contextual Mapping of Selected Studies

This review synthesizes findings from 17 peer-reviewed articles selected for their methodological rigor and relevance, sourced from Scopus, WOS, and ScienceDirect databases, including Q1 (n=13), Q2 (n=2), and Q4 (n=2) journals. The studies were analyzed across four dimensions: geographical origin, publication year, research method, and target educational level. Geographically, the studies span 13 countries, offering diverse educational and technological contexts. Southern and Western Europe contributed the most, notably



Greece (Christopoulos et al., 2024; Leonardou et al., 2020; Legaki et al., 2020) and Germany (Kiili et al., 2018; Groening & Binnewies, 2019), along with Portugal (Barros et al., 2020), Spain (Rosillo & Montes, 2021; Jiménez et al., 2020), Hong Kong (Yung et al., 2020), and Singapore (Chiu & Seah, 2024). The Global South is represented by Indonesia (Wardani et al., 2019), Malaysia (Abidin et al., 2019), South Africa (Bayaga et al., 2024), Colombia (Zapata et al., 2024), Taiwan (Ding & Yu, 2024), South Korea (Choi et al., 2025), and China (Gui et al., 2025).

This wide distribution reflects the global relevance of Game-Based Learning (GBL) in mathematics while revealing contextual differences. Studies from developing countries reported barriers such as limited infrastructure and teacher preparedness, whereas those from high-income nations emphasized sophisticated game design and seamless digital integration (Zapata et al., 2024; Choi et al., 2025). These disparities underscore the moderating role of local contexts in determining GBL effectiveness.



Figure 4. Distribution of Articles by Region

Publication Trends and Game Types in Reviewed Studies

As shown in Figure 3, the reviewed studies span from 2018 to 2025 with fluctuating publication trends. The earliest study appeared in 2018 (Kiili et al.), followed by three in 2019 (Wardani et al.; Abidin et al.; Groening & Binnewies) and five in 2020 (Leonardou et al.; Legaki et al.; Barros et al.; Yung et al.; Jimenez et al.), reflecting growing interest in GBL for mathematics. Only one study was published in 2021 (Rosillo & Montes), while no eligible studies were found for 2022–2023, indicating a potential publication gap. Interest resurged in 2024 with five studies (Christopoulos et al.; Chiu & Seah; Bayaga; Zapata; Ding & Yu), and continued with two in 2025 (Choi et al.; Gui), suggesting renewed focus in the post-pandemic era. DGBL consistently enhanced cognitive outcomes like problem-solving and reasoning (Kiili et al., 2018; Barros et al., 2020), whereas gamification boosted motivation and affective engagement (Groening & Binnewies, 2019).



Regarding game types (Figure 4), three categories emerged: (1) Digital Game-Based Learning (DGBL), dominant in 11 studies (e.g., Kiili et al., 2018; Christopoulos et al., 2024); (2) Digital Gamification featured in four studies (Wardani et al., 2019; Gui et al., 2025); and (3) Non-Digital GBL applied in two studies (Bayaga et al., 2024; Choi et al., 2025). This distribution confirms DGBL's prevalence, likely due to its adaptability, interactivity, and compatibility with modern educational needs.

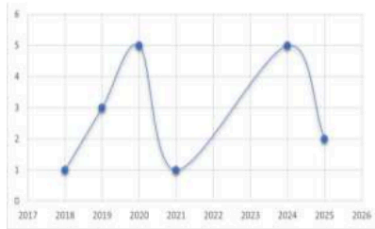


Figure 5. Distribution of Articles by Year



Figure 6. Distribution of Articles by Game Type

Research Design and Educational Context Distribution

As shown in Figure 7, the reviewed studies applied three main research designs: true experimental (7 studies), between-subjects experimental (4 studies), and quasi-experimental (7 studies). True experimental designs, involving random group assignment and controlled interventions, were used by Kiili et al. (2018), Barros et al. (2020), Bayaga et al. (2024), Yung et al. (2020), Leonardou et al. (2020), and Christopoulos et al. (2024). Between-subjects designs without randomization were employed in studies such as Gui et al. (2025), Ding & Yu (2024), Groening & Binnewies (2019), and Legaki et al. (2020). Quasi-experiments, lacking random assignment but involving intervention and control groups, were seen in Jimenez et al. (2020), Choi et al. (2025), Chiu & Seah (2024), Wardani et al. (2019), Abidin et al. (2019), Rosillo & Montes (2021), and Zapata et al. (2024).

Regarding educational levels (Figure 8), studies were categorized into three groups: (1) elementary/lower secondary (4 studies, e.g., Kiili et al., 2018; Choi et al., 2025; Chiu & Seah, 2024; Leonardou et al., 2020), (2) junior secondary (4 studies, e.g., Wardani et al., 2019; Abidin et al., 2019; Jimenez et al., 2020; Barros et al., 2020), and (3) combined junior–senior secondary (9 studies, e.g., Gui et al., 2025; Ding & Yu, 2024; Groening & Binnewies, 2019; Legaki et al., 2020; Bayaga et al., 2024; Yung et al., 2020; Rosillo & Montes, 2021; Zapata et al., 2024; Christopoulos et al., 2024). These classifications highlight methodological diversity



and the broad application of GBL across age groups in mathematics education.

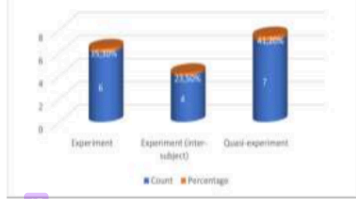


Figure 7. Distribution of articles based on research methods

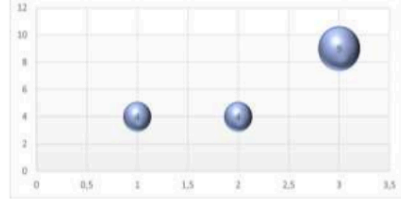


Figure 8. Distribution of articles based on education level

Thematic Trends in Game-Based Learning Research in Mathematics Education

An analysis of 17 reviewed articles identified nine key thematic areas in game-based learning (GBL) for mathematics: (1) problem-solving, (2) learning motivation, (3) general mathematics education, (4) algebra, (5) foundational skills, (6) rational numbers, (7) polynomial operations, (8) statistics, and (9) geometry (cube nets) (see Figure 9). Longer interventions (Gui et al., 2025; Zapata et al., 2024) produced more sustained cognitive and affective improvements, while short-term implementations primarily boosted immediate engagement. Problem-solving and motivation were the most frequent themes, each explored in three studies (Bayaga et al., 2024; Christopoulos et al., 2024; Ding & Yu, 2024; Groening & Binnewies, 2019; Legaki et al., 2020; Gui et al., 2025), emphasizing the role of GBL in enhancing reasoning skills and intrinsic motivation. General mathematics education also featured prominently (Abidin et al., 2019; Chiu & Seah, 2024; Zapata et al., 2024), alongside specific content areas such as algebra (Rosillo & Montes, 2021; Jiménez et al., 2020) and basic skills (Yung et al., 2020; Leonardou et al., 2020). Less-explored topics included rational numbers (Kiili et al., 2018), polynomials (Barros et al., 2020), statistics (Legaki et al., 2020), and geometry (Wardani et al., 2019), indicating potential for further research.

Despite GBL's promise in improving motivation and engagement, its effect on higher-order cognitive skills remains inconsistent, especially in short-duration or low-resource contexts. This suggests that GBL success depends not only on game design but also on systemic factors like infrastructure, teacher readiness, and cultural perceptions of technology (Gui et al., 2025; Ding & Yu, 2024). Moreover, the limited use of standardized affective measures (Radkowsch et al., 2021) raises concerns about the validity of affective outcome assessments. The underrepresentation of themes such as statistics, spatial geometry, and



polynomial operations highlights the need for broader GBL content coverage in future studies.



Figure 9. presents the distribution of articles based on their respective research topics.

Discussion

The Impact of Game-Based Learning (GBL) on Students' Cognitive Domain in Mathematics Education.

Analysis of 17 reviewed articles consistently shows that GBL positively impacts students' cognitive abilities in mathematics, particularly in enhancing conceptual understanding, problem-solving, and higher-order thinking skills such as critical and creative thinking. Kiili et al. (2018) demonstrated that game metrics could predict learning outcomes, with students outperforming control groups in rational number tasks. Similarly, Jimenez et al. (2020) and Barros et al. (2020) reported that digital games like Escape Room and Tempoly significantly improved both engagement and achievement in algebra and polynomial operations. GBL also enhances problem-solving abilities, especially among students with high prior knowledge in collaborative settings (Gui et al., 2025). Bayaga et al. (2024) found that AI-based digital GBL improved thinking skills. Visual-rich content, such as geometry and 3D objects, further benefits from GBL through digital and AR platforms (Wardani et al., 2019; Zapata et al., 2024), while hybrid models (Yung et al., 2020; Rasillo & Montes, 2021) yield positive post-test outcomes across diverse instructional formats.

From a pedagogical perspective, game-based challenges in statistics (Legaki et al., 2020) and reward systems (Leonardou et al., 2020) enhance cognitive performance, supported by immersive 3D technologies (Christopoulos et al., 2024). These findings align with Constructivist Learning Theory, emphasizing knowledge construction via active, engaging tasks, and with Cognitive Load Theory, where well-designed multimodal content facilitates understanding, especially in spatial domains like geometry. However, variations in research



settings, sample sizes, and educational contexts limit broad generalization. Factors such as technological infrastructure, teacher readiness, and cultural attitudes toward digital learning may influence GBL effectiveness, especially in resource-constrained environments. Future research should address long-term impacts, skill transferability across mathematical domains, and differential effects on diverse learner profiles.

The Impact of Game-Based Learning (GBL) on Students' Affective Domain in Mathematics Education.

Game-Based Learning (GBL) positively influences students' affective domain by enhancing motivation, emotional engagement, positive attitudes, and reducing mathematics anxiety, as reported in seven of the 17 reviewed studies. These improvements align with Self-Determination Theory (Deci & Ryan, 2000), which highlights autonomy, competence, and relatedness as drivers of intrinsic motivation. Positive feedback, reward systems, and challenge-based mechanics (Leonardou et al., 2019; Jimenez et al., 2020) were key factors meeting these psychological needs. For example, Jimenez et al. (2020) demonstrated that Digital Escape Rooms not only improved algebra outcomes but also increased student motivation. Similarly, Groening & Binnewies (2019) found gamification elements like badges and leaderboards enhanced engagement and confidence, while Leonardou et al. (2019) showed that well-designed feedback reshaped students' perception of mathematics as enjoyable and stimulating. Choi et al. (2025) reported that non-digital chess-based GBL fostered active engagement and a competitive spirit. Studies using AR and dual-mode escape rooms (Zapata et al., 2024; Rasillo & Montes, 2021) provided immersive experiences, promoting comfort and interest in mathematics.

However, some studies (e.g., Ding & Yu, 2024) only briefly addressed affective outcomes without standardized instruments, limiting result comparability. Variations in game duration, complexity, and contextual relevance may explain inconsistencies. The general trend suggests GBL enhances motivation and reduces anxiety, but reliance on self-reports raises concerns of bias. Future research should employ multi-method assessments, such as behavioral and physiological measures, for more valid affective evaluation.

Key Themes in the Implementation of Game-Based Learning (GBL)

This systematic review identifies four key themes that bridge cognitive, affective, and contextual aspects of GBL in mathematics education an integrative perspective rarely emphasized in prior studies. These themes reflect prevailing trends, existing gaps, and opportunities for future pedagogical refinement.



1. **Dominance of Digital Platforms** Digital platforms dominate GBL implementation, with 10 of 17 studies employing tools such as escape rooms (Jimenez et al., 2020; Zapata et al., 2024), 3D virtual environments (Christopoulos et al., 2024), gamification systems (Leonardou et al., 2020), and AR/AI-based simulations (Bayaga et al., 2024; Yung et al., 2020). These studies affirm the central role of technology in enhancing engagement, interactivity, and real-time feedback, aligning with 21st-century learning demands.
2. **Focus on Problem-Solving and Higher-Order Thinking.** Nine studies emphasized problem-solving and critical thinking, particularly at the upper secondary level, where students are more prepared for complex, challenge-based tasks. GBL was strategically employed to develop analytical reasoning and conceptual depth through interactive problem scenarios (Barros et al., 2020; Gui et al., 2025).
3. **Enhancing Motivation and Engagement.** Seven studies highlighted GBL's effectiveness in boosting motivation and positive attitudes towards mathematics. Elements such as rewards, instant feedback, and collaborative challenges (Groening & Binnewies, 2019; Jimenez et al., 2020; Choi et al., 2025) fostered intrinsic motivation, emotional involvement, and classroom enthusiasm.
4. **Global Adoption and Contextual Variations.** The reviewed studies spanned diverse regions of Europe, Asia, Africa, and Latin America, demonstrating GBL's adaptability across cultures and educational systems (Zapata et al., 2024; Rasillo & Montes, 2021). These variations reflect differences in technological readiness, curriculum structures, and cultural values, shaping both implementation and outcomes.

However, a notable limitation is the predominance of short-term interventions, raising concerns about the sustainability of GBL's cognitive and affective benefits. This highlights the need for longitudinal research to evaluate its long-term impact on mathematical learning outcomes.

Contextual Factors Influencing the Effectiveness of Game-Based Learning (GBL)

The success of GBL in mathematics education is shaped not only by game type but also by key contextual factors identified in 17 reviewed studies: student characteristics, game design, intervention duration, and teacher readiness with infrastructure support.

1. **Student Characteristics** Students' prior knowledge and metacognitive skills influence GBL outcomes, as demonstrated by Gui et al. (2025), who found that learners with stronger prior knowledge performed better in collaborative settings. This underscores the



- importance of adapting GBL to students' readiness levels, aligning with Constructivist Learning Theory (Piaget, 1970; Vygotsky, 1978).
2. Type and Design of Games. GBL effectiveness depends on the game's format: digital GBL (e.g., AR, 3D simulations) fosters conceptual understanding and engagement (Kiili et al., 2018; Zapata et al., 2024), digital gamification (e.g., points, badges) boosts routine task motivation (Groening & Binnewies, 2019), while non-digital GBL (e.g., chess games) enhances interaction and critical thinking, especially in low-tech settings (Choi et al., 2025). Thus, game choice must align with learners' needs and resource availability (Zapata et al., 2024).
 3. Duration and Intensity of Intervention. Short-term GBL interventions increase motivation but yield transient effects (Leonardou et al., 2020); longer, repeated applications produce more stable cognitive and problem-solving gains (Gui et al., 2025; Zapata et al., 2024). However, inconsistent reporting on duration limits cross-study comparability, emphasizing the need for standardized intervention descriptions.
 4. Teacher Readiness and Infrastructure. Teacher competence and infrastructure quality are crucial. Lack of training and limited digital skills hinder GBL use (Wardani et al., 2019), as does insufficient technological access (Ding & Yu, 2024). Successful GBL implementations require technical support, policy backing, and institutional commitment.

In sum, while GBL holds potential to enhance cognitive and affective outcomes in mathematics, its success relies heavily on these contextual factors. Adaptive strategies, mixed-methods research, and validated tools are needed to capture long-term impacts, especially in resource-limited contexts. Policymakers should promote low-cost, culturally relevant non-digital GBL to bridge technological gaps, and future studies should explore moderators such as socio-economic status, digital literacy, and gender.

CONCLUSION

This systematic review synthesized findings from 17 empirical studies (2018–2025) on the impact of Game-Based Learning (GBL) in mathematics education. Results consistently showed that GBL enhances cognitive skills such as conceptual understanding, problem-solving, and higher-order thinking (critical and creative), improving performance in algebra, statistics, and geometry. Digital tools like escape rooms, AR/3D environments, and gamified platforms proved particularly effective in promoting deep learning and engagement. GBL also positively influenced affective outcomes by increasing motivation, reducing math anxiety,



and fostering positive attitudes. However, most studies lacked standardized, psychometrically sound instruments for measuring affective impacts, indicating a need for stronger methodological rigor.

Contextual factors, student characteristics, game design quality, intervention duration, and teacher readiness were critical, with game design and teacher competence as key determinants. A disparity remains between digital GBL in well-resourced settings and the relevance of non-digital games in limited-resource environments, reflecting a global digital divide. Overall, GBL offers a promising approach to integrating cognitive and affective learning. Future efforts should focus on contextualized game design, comprehensive teacher training, and equitable technology access, aligning with Indonesia's *Kurikulum Merdeka* and 21st-century education goals. Further research is needed to establish standardized affective assessment tools and evaluate GBL's long-term impacts across varied contexts.

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