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# Revisiting digital game-based mathematics learning: 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. Seventeen empirical studies published between 2018 and early 2025 were rigorously selected based on strict criteria emphasizing methodological quality and relevance to cognitive and affective aspects of mathematics learning. The findings consistently indicate that GBL significantly enhances 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, fostering more favorable attitudes toward mathematics, and reducing math anxiety. However, assessments of affective domains remain less standardized than 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 also highlights the dominance of digital GBL in resource-rich environments while 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 continue to hinder learning. Despite its importance in equipping students with digital literacy, adaptability to automation, and complex problem-solving skills (Szabo et al., 2020; Yulianto et al., 2024), 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 constrained by limited digital infrastructure, insufficient teacher preparedness, and inconsistent outcome metrics (Radkowitsch et al., 2021). Notably, the existing body of literature disproportionately focuses on cognitive outcomes, while affective domains such as motivation, attitudes, and emotional engagement remain critically underexplored. Only about 15% of studies employ 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 contexts.

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 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

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pandemic (2020–2022) accelerated the expansion of remote learning and heightened the demand for emotionally engaging digital pedagogies, rendering GBL frameworks increasingly relevant for addressing both cognitive and affective learning outcomes (Lee & Mohd, 2023). Extending the review through 2025 enables 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; OECD, 2023).

This review focuses on the period from 2018 to 2025, a transformative era in educational innovation marked by the global acceleration of 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 the groundwork for the rapid expansion of GBL during the pandemic (2020–2022), as remote and hybrid learning modes became widespread (Lee & Mohd, 2023).

Following the PRISMA 2020 guidelines (Page et al., 2021) and a thematic synthesis methodology (Thomas & Harden, 2008), this review addresses key methodological limitations in prior GBL literature reviews (Radkowitsch 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 settings.

## METHODS

Game-Based Learning (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 review type and the guiding objectives that frame the analysis.

### *Review Type and Objectives*

This study employed a Systematic Literature Review (SLR) following the PRISMA

2020 protocol (Page et al., 2021) to synthesize empirical findings on the cognitive (conceptual understanding, reasoning, problem-solving, critical and creative thinking) and affective (motivation, engagement, attitudes) impacts of Digital Game-Based Learning (GBL) in primary and secondary mathematics education. The 2018–2025 publication window was selected to capture the post-pandemic surge in educational technology, representing a critical period of transformation in digital learning practices worldwide. The following subsections outline the search strategy, inclusion and exclusion criteria, screening and appraisal procedures, and synthesis approach adopted to ensure methodological transparency and replicability.

### *Data Sources and Search Strategy*

The literature search was conducted across Scopus, Web of Science (WoS), and ScienceDirect using Boolean operators ("AND," "OR") with the following search 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-language journal articles published between January 2018 and May 2025, available in full-text Open Access. A pilot search was initially conducted to refine the keywords and Boolean strings to enhance relevance and retrieval quality. Citation tracking and grey literature were excluded to maintain methodological rigor and minimize publication bias. Figure 1 illustrates the distribution of the term *"math gamification"* within the Scopus database.

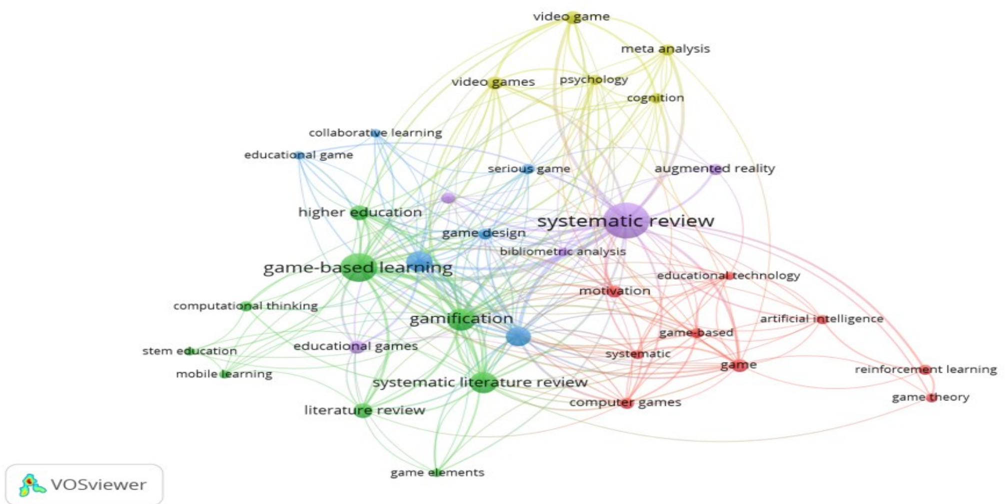


**Figure 1**. Distribution of the Term "Math Gamification" Based on Scopus Database Retrieval

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### *Inclusion and Exclusion Criteria*

The 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. The exclusion criteria comprised 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 corresponding academic performance data).

### *Screening and Selection Process*

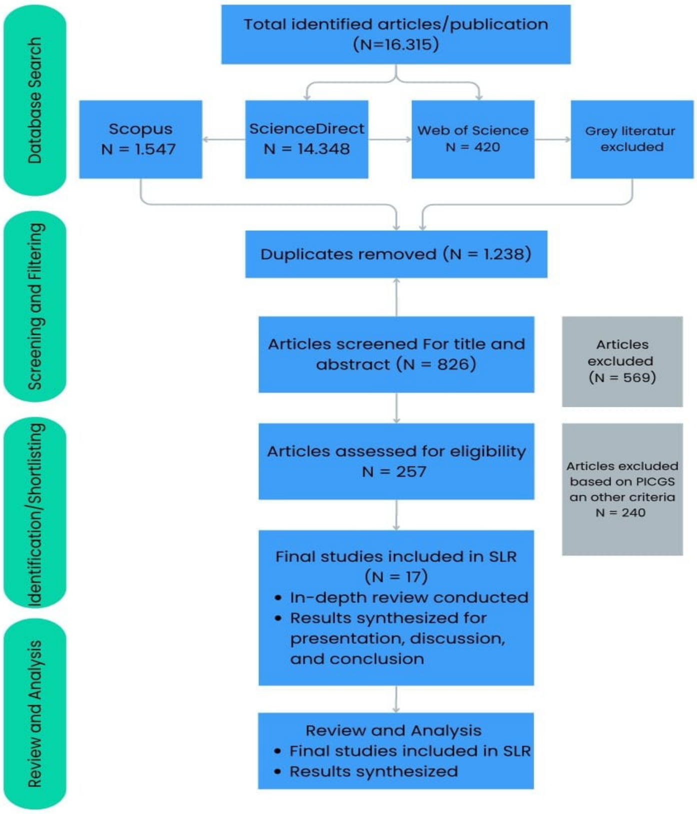


**Figure 2**. PRISMA Flow Diagram

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 the inclusion criteria, 257 articles proceeded to full-text assessment. Of these, 17 studies met all inclusion criteria and were retained for the final synthesis. The screening process followed guidelines adapted from

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Lo et al. (2024) and is illustrated in Figure 2.

### *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 both qualitative and quantitative research. This structured appraisal ensured consistent judgments regarding research clarity, validity, and applicability. Only studies scoring ≥70% on the CASP scale were included in the synthesis. To minimize potential publication and selection bias, a comprehensive multi-database search and a rigorous multi-stage screening process were conducted. Given the qualitative nature of the synthesis, funnel plot analysis was deemed not applicable. Two independent reviewers appraised all studies, resolving any discrepancies through discussion to ensure objectivity.

### *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 and subsequently refined into subthemes such as reasoning, learner engagement, and anxiety reduction through open coding.

Three coders participated 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 resolved through consensus meetings involving all coders until full agreement was achieved. All consensus discussions 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 feasible. Instead, findings were

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synthesized using descriptive statistics and narrative synthesis. Thematic validity was further supported through peer debriefing. Table 1 summarizes the 17 included studies, highlighting 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 | 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- | Dyads composed of members with high prior knowledge are most conducive to digital game- |

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| No | Author(s) | Year | Country | Method | Article Title |
|---|---|---|---|---|---|
| | | | | subjects) | based collaborative learning |

## RESULT AND DISCUSSION

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

### *Results*

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

#### *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 the 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, as seen in Figure 3, 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).

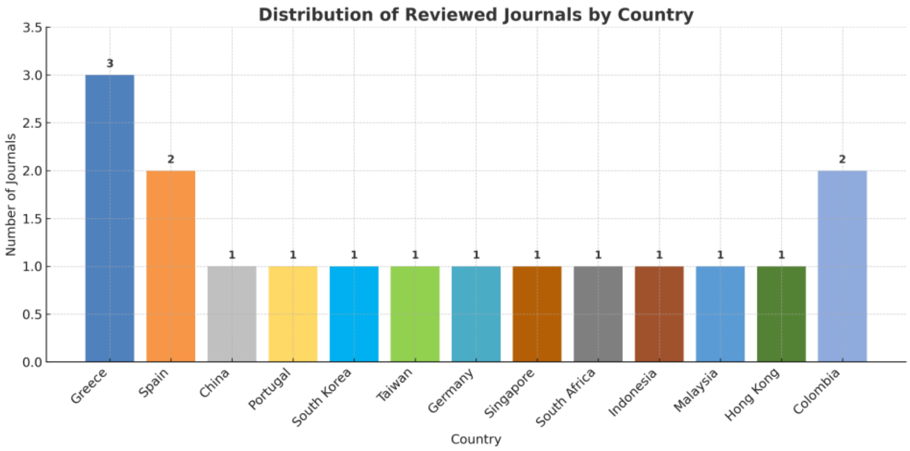


**Figure 3.** Distribution of Articles by Region

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 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 hinder the scalable adoption of GBL initiatives (COL, 2020; Cueto et al., 2023). In contrast, high-income nations such as Finland, the United Kingdom, and the United States report successful GBL integration, supported 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 overlook local epistemologies and socio-technical conditions—a dynamic increasingly critiqued as a form of *digital colonialism*. Cueto et al. (2023) caution against universalist approaches and instead advocate for context-sensitive, participatory, and culturally grounded GBL frameworks. Consequently, the effective implementation of GBL in the Global South must address not only issues of access and technical feasibility but also embrace epistemological diversity and contextual relevance to ensure equitable and sustainable educational outcomes.

### *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 growing scholarly interest in Game-Based Learning (GBL) within mathematics education. However, a notable decline occurred between 2021 and 2023, during which only a single

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study was published (Rosillo & Montes, 2021). This lull was followed by a clear resurgence in 2024–2025 (e.g., Christopoulos et al., 2024; Gui et al., 2025), suggesting renewed academic attention in the post-pandemic context.

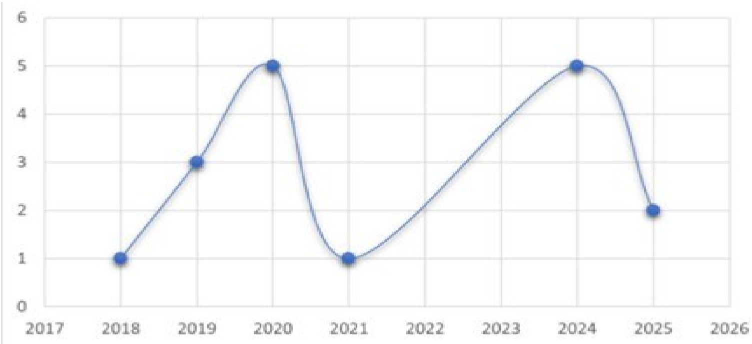


**Figure 4**. Distribution of Articles by Year

Across the corpus, GBL was consistently associated with enhanced cognitive outcomes, particularly in mathematical problem-solving and reasoning (e.g., Kiili et al., 2018; Barros et al., 2020). In parallel, gamification approaches were found to significantly strengthen student motivation and affective engagement (Groening & Binnewies, 2019).

Figure 5 categorizes the Game-Based Learning (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, interactivity, and alignment with contemporary pedagogical frameworks and technology-enhanced learning environments.

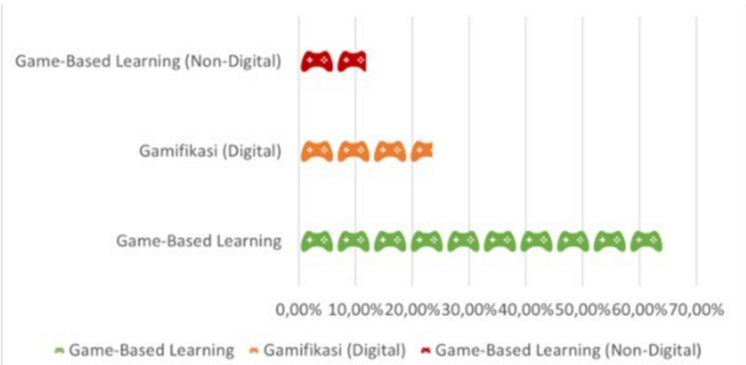


**Figure 5**. Distribution of Articles by Game Type

## *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

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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).

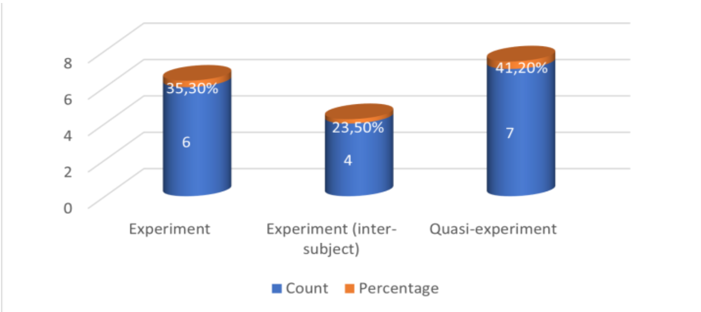


**Figure 6**. Distribution of Articles Based on Research Methods

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 the **methodological diversity** and the **broad applicability** of game-based learning (GBL) across different age groups in mathematics education.

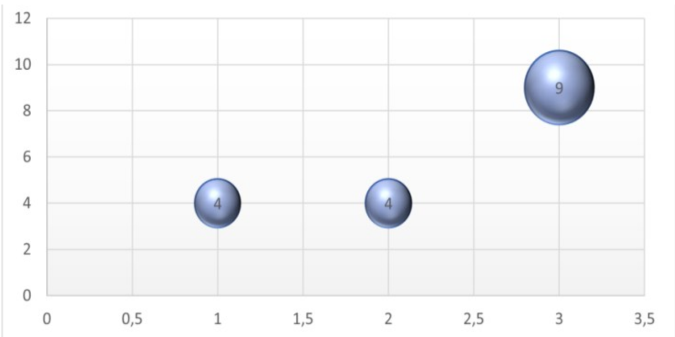


**Figure 7**. Distribution of Articles Based on Education Level

*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 (see Figure 8). Long-term interventions (6–12 weeks, 2–3 sessions per week, 60–90 minutes per session) demonstrated sustained improvements in conceptual understanding, self-efficacy, and learning persistence (e.g., 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).

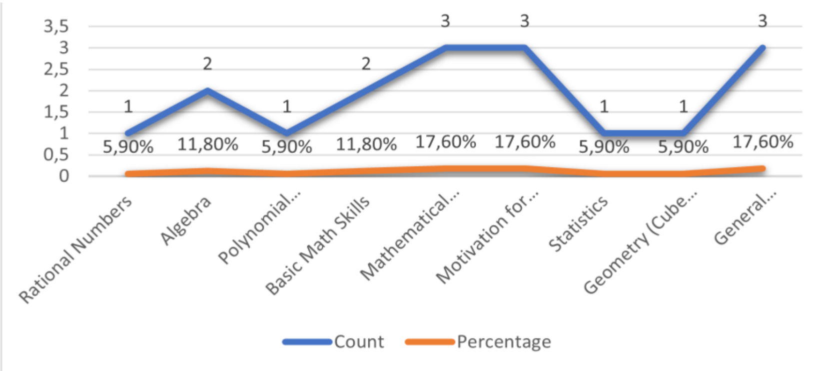


**Figure 8**. presents the distribution of articles based on their respective research topics.

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 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 consistently 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 (Radkowitsch et al., 2021) constrains the validity of affective evaluations, underscoring the need for broader thematic coverage and stronger methodological tools in future GBL research.

## *Discussion*

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

### *Cognitive Domain*

Analysis of the 17 reviewed studies consistently indicates that Game-Based Learning (GBL) significantly enhances students' cognitive abilities in mathematics, particularly 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* improved algebraic reasoning and engagement, while GBL proved especially effective for students with strong prior knowledge in collaborative contexts (Gui et al., 2025). AI-driven platforms also enhanced 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 produced positive post-test results across diverse pedagogical settings (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. However, contextual disparities—such as limited digital access, insufficient teacher readiness, and varying cultural perceptions of technology—affect GBL's effectiveness, particularly in under-resourced environments. For example, Wardani et al. (2019) and Ding & Yu (2024) observed diminished engagement and limited AR implementation due to infrastructural and institutional constraints. These findings emphasize the need for systemic preparedness to ensure equitable and effective GBL integration.

### *Affective Domain*

Game-Based Learning (GBL) has shown significant positive effects on students' affective outcomes, including motivation, emotional engagement, and attitudes toward mathematics, while reducing math anxiety in seven of the 17 reviewed studies. These outcomes align with Self-Determination Theory (Ryan & Deci, 2020), which identifies autonomy, competence, and relatedness as key drivers of intrinsic motivation. Mechanisms such as positive feedback, reward structures, and challenge-based gameplay (Jiménez et al., 2020; Leonardou et al., 2019) effectively addressed these motivational needs. For instance, Jiménez et al. (2020), found that Digital Escape Rooms enhanced both algebra performance and motivation. Similarly, gamification tools such as badges and leaderboards improved engagement and confidence (Groening & Binnewies, 2019), while feedback strategies reshaped students' perceptions of mathematics as enjoyable and stimulating (Leonardou et al., 2019). Choi et al. (2025) also reported increased participation and competitiveness through non-digital, chess-based GBL. Immersive AR and dual-mode escape rooms further elevated student interest and comfort (Rosillo & Montes, 2021; Zapata et al., 2024).

Nonetheless, several studies (Ding & Yu, 2024; Leonardou et al., 2020) addressed affective outcomes only minimally and lacked standardized instruments, limiting generalizability. Differences in intervention duration, task complexity, and contextual relevance likely contributed to inconsistent results. Although GBL generally enhances motivation and reduces anxiety, over-reliance on self-reported measures introduces potential bias. Future research should employ multi-method affective assessments, incorporating behavioral and physiological data, to ensure more valid and comprehensive evaluations.

### *Key Themes in the Implementation of GBL*

This systematic review identifies four overarching themes integrating cognitive, affective, and contextual dimensions of GBL in mathematics education—an intersection rarely explored in existing literature:

1. Prevalence of Digital Platforms: Ten out of seventeen studies utilized digital 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 technologies foster interactivity, real-time feedback, and learner autonomy aligned with 21st-century competencies, including critical thinking, creativity, and digital literacy.

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2. EEmphasis on Problem-Solving and Higher-Order Thinking: Nine studies highlighted GBL's capacity to foster analytical reasoning and deep conceptual understanding, particularly among upper-secondary students, through interactive, problem-based mathematical tasks (Barros et al., 2020; Gui et al., 2025).
3. Enhancement of Motivation and Engagement: Seven studies documented increased intrinsic sic motivation, emotional involvement, and positive attitudes toward mathematics, largely driven by gamified elements such as rewards, feedback, and collaboration (Choi et al., 2025; Groening & Binnewies, 2019; Jiménez et al., 2020).
4. Global Implementation and Contextual Flexibility: GBL was adopted across Varied contexts—including Europe, Asia, and Africa. and Latin America—demonstrating adaptability to different curricular, technological, and cultural settings (Rosillo & Montes, 2021; Zapata et al., 2024).

Despite promising results, most interventions were short-term (1 session to 3–4 weeks). While effective for immediate engagement, such durations often failed to produce lasting gains in reasoning and critical thinking (Jiménez et al., 2020; Leonardou et al., 2020). Moreover, few studies included delayed post-tests, leaving long-term cognitive and affective effects underexplored. This highlights the need for longitudinal research to examine sustained GBL impacts.

### *Contextual Factors Influencing GBL Effectiveness*

GBL effectiveness depends not only on the type of game but also on contextual variables identified across the reviewed studies:

1. Student Characteristics**:** Learners with stronger prior knowledge and metacognitive skills demonstrated greater gains, particularly in collaborative settings (Gui et al., 2025), aligning with constructivist principles. Tailoring GBL to students' readiness levels is therefore essential.
2. Game Type and Design**:** AR and 3D simulations enhanced conceptual understanding (Kiili et al., 2018; Zapata et al., 2024); gamification elements (e.g., points, badges) increased motivation in routine tasks (Groening & Binnewies, 2019); and non-digital games (e.g., chess) fostered critical thinking in low-tech contexts (Choi et al., 2025). Effective game design should thus align with learners' needs and technological conditions.
3. Duration of Intervention**:** Short-term GBL boosted motivation but yielded transient cognitive effects (Leonardou et al., 2020), whereas sustained exposure led to more durable

improvements in reasoning and problem-solving (Gui et al., 2025; Zapata et al., 2024). However, inconsistent reporting of intervention length limits comparability.

4. Teacher Readiness and Infrastructure**:** Teacher competence, digital literacy, and institutional support remain critical. Barriers such as inadequate training and limited infrastructure constrain GBL success (Wardani et al., 2019; Ding & Yu, 2024). Effective implementation requires systemic support and policy integration.

While GBL shows substantial potential to enhance both cognitive and affective outcomes, its success depends on these interrelated factors. Methodologically, this review is limited by its reliance on narrative synthesis, which precludes effect size estimation. Variations in design, sample size, and rigor reduce generalizability, and the exclusion of non-English and gray literature may introduce bias. Furthermore, heavy dependence on self-report measures for affective data raises validity concerns.

Future research should prioritize longitudinal, mixed-methods approaches, integrating behavioral, physiological, and performance-based assessments. Studies should explore long-term effects, domain transferability, and moderating factors such as socio-economic status, gender, and digital access. Additionally**,** low-tech, scalable GBL models should be developed to promote educational equity in resource-limited settings.

## CONCLUSION

This systematic review synthesized findings from 17 empirical studies (2018–2025), addressing four research objectives. First, GBL was found to significantly enhance students' cognitive competencies, particularly in conceptual understanding, problem-solving, and higher order thinking in areas such as algebra, statistics, and geometry. Second, GBL improved affective outcomes by increasing motivation, reducing math anxiety, and fostering more positive learning attitudes. Third, dominant GBL practices included escape rooms, augmented reality (AR), and 3D gamified environments emphasizing collaboration and participation. Finally, GBL effectiveness was shaped by contextual factors, including game design quality, teacher readiness, and digital infrastructure availability.

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