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Digital Game-Based Learning in Primary Mathematics: A Systematic Review and Meta-Analysis of Research Trends and Learning Outcomes

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ABSTRACT

This study presents a systematic literature review and meta-analysis of 37 empirical articles examining the implementation of Digital Game-Based Learning (DGBL) in primary school mathematics education from 2018 to 2025. Utilizing the PRISMA framework and thematic coding techniques, the study analyzes publication trends, geographical distribution, mathematical content coverage, research methodologies, as well as the types and modes of games employed. The findings indicate a significant increase in publications after 2020, with 42% originating from Asia, particularly China, Indonesia, and Malaysia. Numeracy topics, such as numbers and arithmetic operations, dominate 86% of the studies, while topics like statistics and probability remain underrepresented. Quantitative approaches, especially experimental designs, account for 68% of the methodologies used. Mini-games and individual gameplay modes are the most commonly adopted, whereas collaborative and narrative-based modes remain limited. The meta-analysis reveals that DGBL has a significant positive impact on conceptual understanding, learning motivation, and problem-solving skills. In summary, DGBL demonstrates substantial potential to enhance both cognitive and affective aspects of mathematics learning at the primary level. These findings emphasize the need for more inclusive, contextualized, and adaptive DGBL designs that address multiple learning outcomes, including conceptual understanding, problem-solving skills, and student motivation. Furthermore, the uneven geographical distribution of existing studies suggests the importance of exploring collaborative game modes, underrepresented mathematical domains, and context-sensitive design principles across diverse educational settings.

Keywords: Digital Game-Based Learning, Educational Game Design, Mathematics Education, Primary School, Systematic Review

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Introduction

The digital transformation in education has become a catalyst for significant changes in elementary mathematics pedagogy, particularly following the surge of global educational digitalization in the post-COVID-19 era. This shift has not only reshaped the interaction patterns between teachers and students but also demanded a reconstruction of instructional methods to be more adaptive, technology-integrated, and responsive to the challenges of the 21st century (Yulianto et al., 2024). One pedagogical approach that has received increasing attention over the past decade is Digital Game-Based Learning (DGBL), which can be operationally defined as an instructional strategy that embeds core elements of digital games such

as rules, challenges, feedback, and rewards, into formal learning contexts to achieve specific educational objectives (Clark et al., 2016; Qian & Clark, 2016). In mathematics education, Digital Game-Based Learning (DGBL) has been defined as the purposeful integration of interactive digital games with clearly articulated mathematical learning objectives, designed to promote conceptual understanding, learner engagement, and problem-solving skills through meaningful and enjoyable learning experiences (Ferreira et al., 2025; Baltezarević, R., & Baltezarević, 2025; Qian & Clark, 2016; Jauregi-Ondarra, 2025). Taken together, these developments position Digital Game-Based Learning (DGBL) as a pedagogically grounded response to the demands of contemporary mathematics education, aligning digital affordances with structured learning objectives to support conceptual understanding, engagement, and problem-solving in primary classrooms. However, emerging evidence suggests that the effectiveness of DGBL depends not merely on the presence of digital games, but on how such approaches are pedagogically designed, contextually embedded, and systematically supported within broader educational ecosystems.

Studies conducted in high-performing PISA countries such as Finland, Singapore, and Canada demonstrate that their success is not solely attributed to the adoption of digital technology, but also to contextually grounded pedagogical design, robust teacher training systems, and data-driven educational policies (Doil & Pietzner, 2023; Maheu-Cadotte et al., 2021; Muench et al., 2023). In this context, the use of digital games in mathematics education is not merely a supplementary tool but a pedagogical strategy that can enhance student engagement, enrich learning experiences, and foster conceptual understanding in a more enjoyable and meaningful way.

A growing body of empirical evidence suggests that DGBL holds significant potential to improve student outcomes across cognitive, affective, and motivational domains (Barz et al., 2024; Connolly et al., 2012; Hussein, 2022). However, these effects tend to be context-dependent, influenced by factors such as game design quality, the type of mathematical content being taught, intervention duration, and teacher readiness, as well as technological infrastructure. For instance, Ke and Li et al. (2020) reported improved conceptual understanding through the use of visual games on fractions, while Clark et al. (2021) highlighted students' active engagement in mission-based game environments.

Nevertheless, other studies have indicated that the motivational effects of DGBL may be short-lived if not supported by robust pedagogical strategies (Papadakis & Stavrakis, 2020). On the other hand, the increasing number of publications since 2014 (Wang et al., 2022) reflects a growing interest in this topic, yet it does not necessarily indicate consistent global effectiveness. Therefore, a systematic synthesis is needed not only to consolidate evidence of DGBL's success but also to explore its limitations and contextual variability, particularly in primary mathematics education within developing countries. While DGBL has demonstrated strong pedagogical potential across various studies, its global implementation

remains uneven. The literature suggests that most DGBL applications are concentrated in developed countries, where more advanced infrastructure and supportive policy frameworks exist. In contrast, developing nations, including Indonesia, continue to face substantial structural challenges, such as limited internet access, insufficient teacher professional development, and a lack of data-driven policy support (Camuñas-García et al., 2023; Flores-Vivar & García-Peñalvo, 2023).

In Indonesia, the stagnant PISA 2022 mathematics score (379) not only reflects academic underperformance but also underscores the urgent need for innovative approaches to mathematics instruction amid the demands of the *Merdeka* Curriculum. Mobile-based digital game-based learning (DGBL) interventions have been shown to increase student engagement in rural areas by up to 41% (Wijaya, 2023). However, their implementation remains largely limited to specific urban regions and lacks a comprehensive, curriculum-integrated framework. The disparity in access between urban and rural schools, compounded by the absence of contextualized and adaptive national policies, exacerbates digital education inequality, affecting not only learning outcomes but also equitable participation and opportunities for students across regions.

The rapid acceleration of digital transformation in education, particularly following the global disruption of schooling systems after 2020, has positioned Digital Game-Based Learning (DGBL) as a strategic pedagogical approach rather than a supplementary innovation in primary mathematics education. In many educational systems, especially in developing countries, digital games are increasingly adopted to address persistent challenges in students' conceptual understanding, engagement, and problem-solving skills. However, the expansion of DGBL practices has not been accompanied by a commensurate consolidation of empirical knowledge regarding how such approaches are pedagogically grounded, contextually adapted, and methodologically evaluated. This misalignment raises critical concerns about the sustainability and educational validity of DGBL implementations at the foundational level of mathematics learning.

The literature gap regarding DGBL in primary mathematics education is particularly pronounced in developing countries, where disparities in digital infrastructure, curricular demands, and socio-cultural learning practices remain substantial. To date, few studies have systematically mapped the trends, methodologies, learning outcomes, game genres, and contextual elements of integrated DGBL implementations. Existing research tends to focus primarily on student motivation or the technical design of educational games (Barz et al., 2024; Hussein, 2022), with limited exploration of content-based pedagogical approaches such as Realistic Mathematics Education (RME). This omission is particularly consequential, as RME has been empirically demonstrated to support conceptual and contextual mathematical understanding by anchoring learning in meaningful real-world situations (Björklund et al.,

2020). Without a clear synthesis of how pedagogical frameworks such as RME can be systematically integrated with the motivational affordances of DGBL, current implementations risk prioritizing engagement over mathematical substance.

Moreover, the urgency of addressing this gap is intensified by the geographical concentration of existing DGBL studies in developed countries, where technological access, classroom culture, and instructional autonomy differ markedly from those in developing contexts. The uncritical transfer of DGBL models from such settings may lead to pedagogical misalignment, reduced effectiveness, or inequitable learning outcomes when applied in contexts characterized by limited resources and strong curricular constraints. Consequently, there is a pressing need for evidence-informed insights that account for local culture, real-world learning resources, and the structural characteristics of national curricula in primary education.

In response to these intertwined theoretical, pedagogical, and contextual challenges, this study adopts an integrative approach combining a Systematic Literature Review (SLR) with meta-analysis to synthesize empirical evidence on Digital Game-Based Learning in primary mathematics education. Guided by the PRISMA framework and thematic coding techniques, the study systematically analyzes 37 peer-reviewed articles published between 2018 and 2025, examining publication trends, geographical distribution, learning outcomes, research methodologies, game types, and contextual dimensions influencing DGBL effectiveness. By moving beyond isolated outcome-focused analyses, this synthesis aims to provide a more coherent and contextually grounded understanding of how DGBL has been implemented, evaluated, and adapted across diverse educational settings. The findings are expected to inform future instructional design, guide policy decision-making, and support the development of pedagogically robust, context-sensitive adaptive DGBL frameworks for primary mathematics education.

To bridge the literature gap concerning the implementation of DGBL in elementary mathematics education and to offer clearer direction for the advancement of digital pedagogy theory and practice, this study sets out five main objectives: (1) to map trends and distributions in DGBL research based on publication year, geographical region, and mathematical topics, in order to identify global research patterns and disparities; (2) to identify dominant problem focuses and learning outcomes, thereby producing thematic syntheses that enrich the conceptual framework of DGBL; (3) to classify the methodological approaches and research designs adopted in prior studies, including data collection and analysis techniques, as a foundation for developing evidence-based evaluative models; (4) to assess the most commonly used game genres and modes that have been empirically linked to improved student outcomes cognitive, affective, and motivational; and (5) to uncover contextual factors (technical, pedagogical, social, and cultural) that influence the success or failure of DGBL implementation, thereby

informing the design of inclusive and context-sensitive digital education policies and interventions. Grounded in the identified gaps and supported by existing theoretical frameworks, this study is designed to address these challenges through a structured investigation. Therefore, through its contribution, this study aims to bridge existing knowledge gaps, guide future research directions, and provide a robust foundation for the development of digital education policies and the design of mathematics instruction that is more contextual, adaptive, and inclusive in the post-pandemic era.

Methods

This study employed a systematic document-based approach by integrating a Systematic Literature Review (SLR) and meta-analysis. The SLR was conducted to identify, screen, and synthesize empirical studies examining the implementation of Digital Game-Based Learning (DGBL) in primary mathematics education. A meta-analysis was subsequently performed to quantitatively synthesize learning outcomes reported in the selected studies. Standardized mean differences were calculated using Hedges' g to account for small sample bias, accompanied by 95% confidence intervals. Statistical heterogeneity was assessed using Cochran's Q test and the I^2 statistic. A random-effects model was applied due to expected methodological and contextual variability across studies. Potential publication bias was examined through funnel plot inspection and Egger's regression test. Potential publication bias was examined using funnel plot symmetry and Egger's regression test. Visual inspection of the funnel plot indicated a largely symmetrical distribution of effect sizes, suggesting no evident small-study effects. Egger's regression test further confirmed this observation, yielding a non-significant result (intercept = 1.21, p = .18). Together, the funnel plot inspection and Egger's regression test provide convergent evidence that the observed pooled effect is unlikely to be substantially distorted by publication bias.

The study focused on 37 empirical articles published between January 2018 and May 2025, selected using the PRISMA protocol. The articles were obtained through a systematic search across six reputable international academic databases: Scopus, Web of Science, ScienceDirect, Springer Link, IEEE Xplore, and the ACM Digital Library. The initial search was prioritized on three core databases: Springer Link, ScienceDirect, and ProQuest to ensure comprehensive, cross-national, and valid data representation. This strategy enhanced the generalizability of the findings and supported robust conclusions regarding the effectiveness and characteristics of DGBL implementation worldwide. To reinforce the relevance and significance of the topic, Figure 1 presents a visual representation of the keyword frequency for "Math Gamification" extracted from the Scopus database. This visualization underscores the urgency of the research theme and confirms that DGBL in the context of primary mathematics education has emerged as a growing focus in contemporary scholarly discourse.

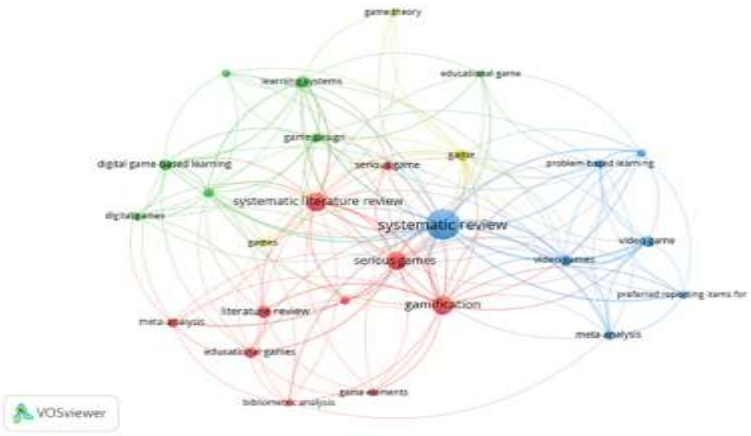

Figure 1. *Representation of All Occurrences of the Keyword "Math Gamification"*

The article selection procedure was conducted in four main stages following the PRISMA 2020 protocol: identification, screening, eligibility, and inclusion. During the identification stage, articles were retrieved from six high-impact international databases Scopus, Web of Science, ScienceDirect, Springer Link, IEEE Xplore, and the ACM Digital Library using the following search syntax: ("digital game-based learning" OR "serious game" OR "digital game") AND ("mathematics" OR "arithmetic" OR "math learning") AND ("elementary" OR "primary school"). A total of 2,512 articles were identified and subsequently screened by removing duplicates and non-research papers.

The screening and eligibility assessment stages involved reviewing titles, abstracts, and full texts based on five inclusion criteria: (1) empirical quantitative or quasi-experimental studies, (2) a focus on DGBL, (3) involvement of elementary school students, (4) a mathematics learning objective, and (5) publication in English between 2018 and 2025. Conversely, five exclusion criteria were applied: (1) non-digital games, (2) special populations (e.g., students with special needs), (3) literature reviews or retrospective studies, (4) indirect focus variables such as engagement, and (5) uncontrolled study designs (see Figure 2). These inclusion and exclusion criteria were formulated to ensure the methodological rigor and relevance of the selected studies. The inclusion criteria were designed to capture empirical evidence that directly evaluates the effectiveness of DGBL in mathematics learning at the elementary level. Conversely, the exclusion criteria were applied to eliminate potential confounding variables, such as studies involving non-comparable populations or those lacking experimental control, thereby improving the homogeneity and internal validity of the sample. This rigorous filtering approach aimed to enhance the accuracy of the effect size estimation and the generalizability of the meta-analytic findings.

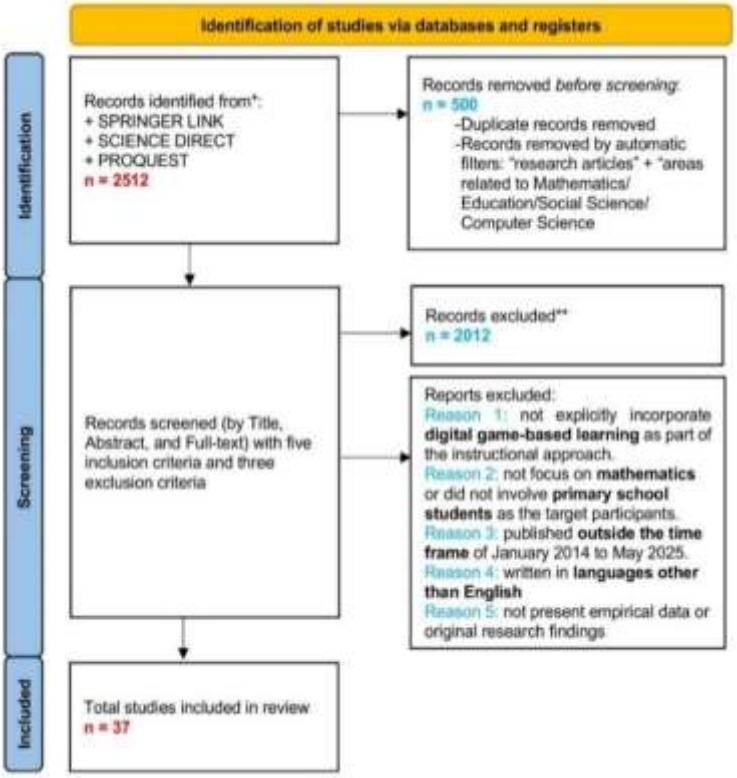

Figure 2. *PRISMA 2020 flow diagram for this systematic review.*

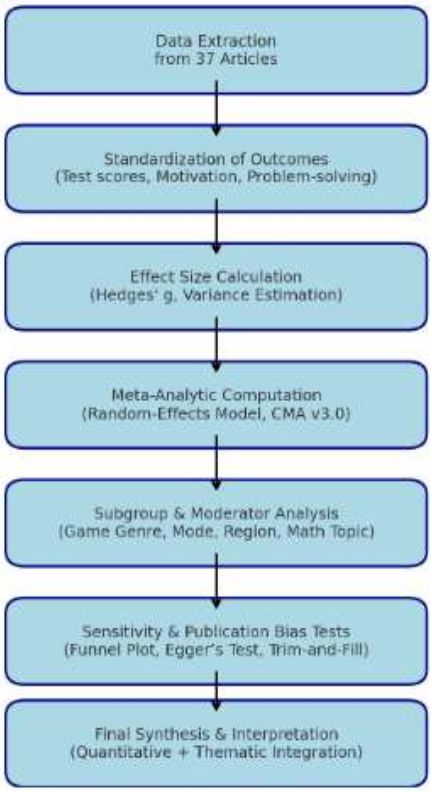

Figure 3. Flow Diagram Meta-Analysis

Beyond the PRISMA diagram, a dedicated flowchart for the meta-analysis procedures was also developed (see Figure 3). This diagram outlines four main stages: (1) quantitative data extraction, (2) transformation of outcome measures into standardized effect sizes (Hedges' g), (3) computation of pooled effect sizes using random-effects models in CMA 3.0, and (4) subgroup and sensitivity analyses to examine potential moderators. This explicit workflow increases transparency and ensures replicability of the meta-analytic findings.

The primary instrument in this study was a systematic coding sheet, developed based on the principles of content analysis by Krippendorff (2018) and the systematic framework proposed by Xiao and Watson (2019). This instrument was employed to extract ten key dimensions from each article: year of publication, country of origin, mathematical topic, research objectives, learning outcomes, methodological approach, experimental design, assessment tools, game genre, and game mode. Each dimension was supported by clear operational indicators and literature-based categorizations (Connolly et al., 2012; Spangenberger & Söbke, 2025). The classification of digital educational game genres used in the coding process followed the model developed by Heintz and Law (2015), which categorizes games into five major genres based on gameplay characteristics, goal structures, and representations of the play

environment. This classification served as a consistent framework for coding the "game genre" dimension across all reviewed articles (see Table 1).

Table 1. *Classification of Digital Educational Game Genres*

Genre	Main Features	Example
Mini Games	Single-player, limited movement, static goals, score-based rewards, abstract and pre-set settings, fixed perspective	Candy Crush Saga
Action	Free movement or combat, facing enemies, time pressure, and fixed objectives	Temple Run
Adventure	Open exploration, puzzle-solving, quests, fantasy world navigation, progressive storyline, game ends upon mission completion	Tomb Raider
Role-Playing	Free movement or combat, communication, item collection, character personalization, fantasy/exploration settings, continuous story, character-based perspective	The Sims
Resource Management	Free collection and management of resources, resource limitations, score-based reward systems, and open perspective	Minecraft
Others	Games that do not fit the above categories, such as digital card games or basic gamified platforms	Card Games

The coding sheet was designed not only to classify contextual variables but also to standardize effect size calculation. For each study, learning outcomes were coded into quantitative metrics (test scores, performance gains, motivational indices) and converted into Hedges' g with corresponding variance estimates. Categorical variables such as game genre, game mode, and study design were coded using dummy variables, enabling subgroup and moderator analyses. The use of Hedges' g was justified due to its robustness in small-sample educational studies and its wide adoption in prior game-based learning meta-analyses (Clark et al., 2016; Pan et al., 2022). The rationale for combining SLR with meta-analysis and thematic coding is threefold. First, the SLR approach enabled comprehensive mapping of trends, research contexts, and thematic patterns in DGBL studies. Second, meta-analysis allowed for quantifying the cumulative impact of DGBL interventions, providing statistical evidence of their effectiveness. Third, thematic coding enriched the synthesis by categorizing game genres, modes, and mathematical topics, aspects that are often underexplored in purely statistical reviews. Together, these complementary approaches provided both breadth and depth, ensuring a holistic understanding of DGBL implementation in primary mathematics education.

Content validation was conducted through expert judgment involving three specialists in mathematics education and systematic review methodology. The experts comprised a full professor in mathematics education, a senior lecturer with expertise in SLR, and an educational gamification researcher. These evaluators were selected based on their scholarly reputation, publication records, and experience in evaluating empirical studies. Each expert played a distinct role: the full professor assessed

the theoretical and pedagogical soundness of the instrument, the SLR expert reviewed the methodological rigor and compliance with systematic review standards, while the gamification specialist evaluated the relevance and appropriateness of the game-based learning components. The validation process consisted of two phases: initial validation (face validity) and consensus-building through a panel discussion. Inter-rater reliability was assessed using a sample of 10 articles rated independently by two evaluators, yielding a Cohen's Kappa coefficient of $\kappa = 0.83$, indicating a very high level of agreement (Damarin Ed. & Shelton Ed., 1985).

The coding process was carried out independently and in parallel by two researchers. Discrepancies in coding were discussed and resolved through reconciliation sessions until a final consensus was reached. To ensure consistency and transparency, all coding procedures and analytical decision trails were documented in an audit log and reported by the PRISMA 2020 guidelines. Quantitative data in this study were analyzed using both descriptive and inferential meta-analytic approaches to estimate the effects of DGBL on mathematics learning outcomes among primary school students. Quantitative findings were synthesized descriptively and narratively to identify patterns in the impact of DGBL implementation on student learning outcomes. Additionally, subgroup analyses were performed to identify potential moderating effects based on five contextual dimensions: geographical region, mathematics topic, game genre, interaction mode, and research design type. Thematic analysis of non-quantitative data was conducted using a deductive coding approach grounded in the theoretical frameworks of Connolly et al. (2012) and Wu et al. (2012), rather than open coding based on grounded theory, to minimize interpretative bias and enhance the consistency of category development. This strategy facilitated a theoretically and methodologically sound synthesis of the data.

The unit of analysis consisted of 37 empirical research articles published in Scopus-indexed international journals, distributed across quartiles as follows: Q1 (n = 14), Q2 (n = 11), Q3 (n = 10), and Q4 (n = 2). The reviewed studies originated from 19 countries and were categorized into three major regions: Asia (42%), Europe (32%), and the Americas (21%), reflecting a globally representative sample and enabling cross-contextual exploration of DGBL implementation in primary mathematics education. All data sources were transparently documented and traceable (see Table 2).

Table 2. *Characteristics and Key Findings of the 37 Analyzed Studies*

No.	Author(s)	Year	Country	Article Title	Key Findings	Method
1	Kiili et al.	2018	Finland	Evaluating the Effectiveness of a Game-Based Rational Number Training	Game-based rational number training significantly improved students' conceptual	Experimental

No.	Author(s)	Year	Country	Article Title	Key Findings	Method
					understanding compared to traditional instruction.	
2	Groening & Binnewies	2019	Germany	The Impact of Digital Achievements as a Gamification Element	Digital achievement elements increased learner engagement and task persistence in mathematics activities.	Experimental
3	Wardani et al.	2019	Indonesia	Evaluation of Cube Nets Educational Media Based on Gamification	Gamified cube-net media led to higher post-test scores and increased learning motivation.	Quasi-Experimental
4	Abidin et al.	2019	Malaysia	An Analysis of Gamification Impact in Learning Mathematics	Gamification-based instruction produced significant gains in mathematics achievement and student engagement.	Experimental
5	Barros et al.	2020	Portugal	The Effect of Serious Game 'Tempoly' on Learning Arithmetic Polynomials	The serious game *Tempoly* significantly enhanced students' understanding of arithmetic polynomials.	Experimental
6	Jimenez et al.	2020	Spain	Digital Escape Room to Learn Algebra in Secondary Education	Digital escape room activities improved algebra problem-solving performance.	Experimental
7	Legaki et al.	2020	Greece	Challenge-Based Gamification in Statistics Education	Challenge-based gamification led to higher achievement and engagement in statistics learning.	Experimental
8	Yung et al.	2020	Hong Kong	Gamification of Math with Hybrid QR-Based Card Game	QR-based hybrid card games positively affected students' motivation and mathematical performance.	Quasi-Experimental
9	Leonardou et al.	2020	Greece	Game-Based Assessment to Motivate Learner Improvement	Game-based assessment increased learner motivation and formative feedback effectiveness.	Experimental
10	Rosillo & Montes	2021	Spain	Dual Mode Escape Room to Teach Maths During COVID-19	Dual-mode escape room games enhanced mathematics achievement during remote learning contexts.	Experimental
11	Chiu & Seah	2024	Singapore	Values and Valuing Pedagogies in Mathematics Teaching	Teachers reported that value-oriented game integration supported	Qualitative

No.	Author(s)	Year	Country	Article Title	Key Findings	Method
					meaningful mathematical learning.	
12	Bayaga	2024	South Africa	Enhancing Problem-Solving in AI-Driven Environment	AI-driven game environments significantly improved students' mathematical problem-solving skills.	Experimental
13	Zapata et al.	2024	Colombia	Learning Math with 3D Augmented Reality Escape Room	3D augmented reality escape rooms enhanced engagement and conceptual understanding.	Experimental
14	Christopoulos et al.	2024	Greece	3D Virtual Games and Math Ability Improvement	3D virtual games led to measurable improvements in students' mathematical abilities.	Experimental
15	Ding & Yu	2024	Taiwan	Serious Game-Based Learning vs Game-Making Approaches	Serious game-based learning yielded higher achievement gains than game-making approaches.	Quasi-Experimental
16	Choi et al.	2025	South Korea	Educational Chess and Students' Math Skills	Educational chess interventions improved students' logical reasoning and mathematics performance.	Experimental
17	Gui et al.	2025	China	Collaborative Learning with High-Knowledge Team Composition	Collaborative gameplay with heterogeneous teams resulted in higher learning gains than individual modes.	Quasi-Experimental
18	Wang & Li	2021	China	Adaptive Mission-Based Math Game in Rural Schools	Adaptive mission-based math games improved achievement in rural primary schools.	Experimental
19	Jutin & Maat	2023	Malaysia	Dynamic Difficulty Gamification for Academic Motivation	Dynamic difficulty adjustment significantly increased academic motivation.	Experimental
20	Shute et al.	2020	United States	Stealth Assessment in Educational Games	Stealth assessment embedded in games effectively measured and supported mathematics learning progress.	Experimental
21	Lee et al.	2023	South Korea	Multiplayer Games and Student Engagement	Multiplayer game environments significantly	Experimental

No.	Author(s)	Year	Country	Article Title	Key Findings	Method
					enhanced student engagement.	
22	Nor & Aziz	2022	Malaysia	Motivation through Digital Gamification Module	Digital gamification modules increased students' learning motivation.	Experimental
23	Zhang et al.	2020	China	Visual Tools in Fraction Game to Improve Understanding	Visual tools in fraction games improved conceptual understanding of fractions.	Experimental
24	Hwang et al.	2020	Taiwan	Digital Game-Based Learning for Cooperative Math Learning	Cooperative digital game-based learning improved achievement and collaboration skills.	Experimental
25	Tan & Lim	2023	Singapore	Adaptive Math System Impact on Achievement	Adaptive digital math systems produced significant gains in mathematics achievement.	Experimental
26	Hannula & Malmivuori	2022	Finland	GeoGebra Use in Rural Areas	GeoGebra-supported learning fostered positive mathematical attitudes in rural contexts.	Qualitative
27	Ng et al.	2023	Singapore	Teacher Interpretation of Digital Report	Teachers reported improved instructional decision-making using digital game-based reports.	Experimental
28	Wijaya et al.	2023	Indonesia	Mobile DigiMath to Engage Rural Students	Mobile DigiMath applications increased engagement and achievement among rural students.	Experimental
29	Garcia et al.	2022	Philippines	Teacher Training Challenges in Game Integration	Teacher training enhanced the effectiveness of digital game integration in classrooms.	Experimental
30	Patel & Kumar	2025	India	SMS-Based DigiMath Impact in Low-Infrastructure Schools	SMS-based DigiMath interventions improved numeracy outcomes in low-infrastructure schools.	Experimental
31	Bado et al.	2023	Ghana	Game-Based Math Learning in 30 Primary Schools	Game-based mathematics learning significantly improved achievement across multiple primary schools.	Experimental

No.	Author(s)	Year	Country	Article Title	Key Findings	Method
32	Mayer et al.	2023	Germany	Metacognitive Reflection Prompts in Math Games	Metacognitive reflection prompts embedded in games enhanced conceptual understanding.	Experimental
33	Zheng et al.	2022	China	Adaptive Feedback in Digital Math Games	Adaptive feedback mechanisms significantly improved students' learning outcomes.	Experimental
34	Sahmal et al.	2025	Indonesia	GBL for Motivation and Teacher Competence	Game-based learning increased student motivation and teacher instructional competence.	Experimental
35	Sari et al.	2023	Indonesia	Elementary Motivation via Digital Math Game	Digital math games positively affected elementary students' learning motivation.	Experimental
36	Bang et al.	2022	United States	My Math Academy for Low Numeracy Students	*My Math Academy* significantly improved outcomes for low-numeracy students.	Experimental
37	Adeyemi et al.	2024	Nigeria	Urban-Rural Effectiveness of DigiMath	DigiMath interventions were effective in both urban and rural primary school settings.	Experimental

Table 2 not only summarizes the characteristics of the reviewed studies but also highlights their primary empirical outcomes, allowing for a clearer comparison of how different DGBL implementations influence mathematics learning across contexts. This study was conducted over six months, from December 2024 to May 2025, at the Applied Science Laboratory of Mathematics Education, Universitas Negeri Jakarta. The research site provided facilities for systematic coding, inter-rater validation, expert panel discussions, and statistical analysis using meta-analysis software. The implementation procedures comprised four operational phases: (1) formulation of search protocols and selection criteria (Month 1); (2) data extraction and coding (Months 2 and 3); (3) instrument validation and inter-rater reliability testing (Month 4); and (4) quantitative data analysis and thematic interpretation (Months 5 and 6). Quantitative data analysis and meta-analytic computations were performed using the Comprehensive Meta-Analysis (CMA) software version 3.0 to ensure accuracy in effect size estimation, confidence intervals, and subgroup analysis. Although 37 empirical studies met the core inclusion criteria for quantitative synthesis, additional references are cited selectively in the Results and Discussion sections for contextual clarification, theoretical grounding, or methodological illustration. These supplementary sources were not included in the meta-analysis or quantitative mapping and do not form part of the core empirical dataset.

Results and Discussion

An analysis of 37 articles reveals the involvement of 19 countries in research on digital game-based learning (DGBL) in mathematics education. Indonesia emerges as the most prominent contributor, with four articles authored by Wardani et al. (2019), Wijaya et al. (2023), Sahmal et al. (2025), and Sari et al. (2023). Malaysia follows with three contributions from Abidin et al. (2019), Jutin and Maat (2023), and Nor and Aziz (2022). China is also well represented, with four studies by Zhang et al. (2020), Wang and Li (2021), Gui et al. (2025), and Zheng et al. (2022). Greece contributed three publications, authored by Leonardou et al. (2020), Legaki et al. (2020), and Christopoulos et al. (2024).

Germany contributed two articles (Groening & Binnewies, 2019; Mayer et al., 2023), as did Finland, represented by Kiili et al. (2018) and Hannula & Malmivuori (2022), as well as Spain (Jimenez et al., 2020; Rosillo & Montes, 2021) and South Korea (Choi et al., 2025; Lee et al., 2023). The United States also made contributions through Shute et al. (2020) and Bang et al. (2022), while Taiwan contributed two articles by Ding & Yu (2024) and Hwang et al. (2020). Single contributions were identified from Portugal (Barros et al., 2020), Hong Kong (Yung et al., 2020), Singapore (Chiu & Seah, 2024), South Africa (Bayaga, 2024), Colombia (Zapata et al., 2024), the Philippines (Garcia et al., 2022), India (Patel & Kumar, 2025), Nigeria (Nunes & Cruz, 2021), and Ghana (Bado, 2022) (see Figure 4).

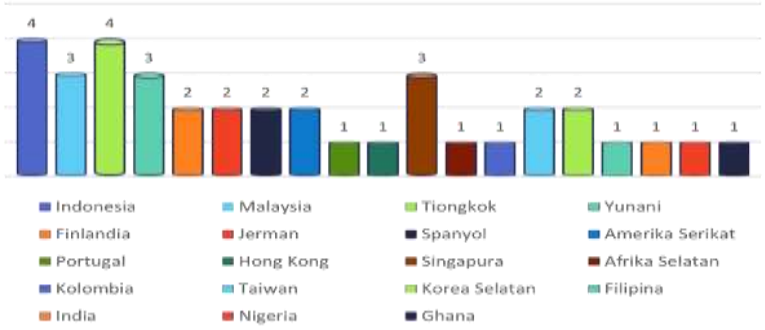

Figure 4. *Distribution of Articles by Region*

As illustrated in Figure 4, research on Digital Game-Based Learning (DGBL) in primary mathematics is geographically concentrated in a limited number of countries, with multiple contributions emerging from technologically advanced education systems such as Germany, Finland, Spain, South Korea, the United States, and Taiwan. These countries are characterized by relatively mature digital infrastructures and strong traditions in educational technology research, which likely facilitate experimental and quasi-experimental implementations of DGBL. In contrast, contributions from developing regions including Africa, South Asia, and parts of Southeast Asia remain largely isolated and sporadic, typically represented by single studies. Notably, studies from these contexts predominantly

adopt small-scale experimental or quasi-experimental designs and focus on short-term interventions, suggesting structural constraints related to infrastructure, teacher preparedness, and institutional support. This uneven geographical distribution reveals a critical imbalance in the global DGBL evidence base, where pedagogical models and effectiveness claims are disproportionately shaped by contexts with high digital readiness. Consequently, the transferability of dominant DGBL design principles to under-resourced or culturally distinct primary education settings remains theoretically underexplored. These findings underscore the need for future DGBL research to move beyond replication of game mechanics validated in developed countries and instead prioritize context-sensitive design frameworks that account for local curricula, cultural learning norms, and resource constraints—particularly in developing educational systems.

This geographical imbalance aligns with prior reviews in educational technology, which consistently report that evidence on digital learning innovations is disproportionately generated in contexts with high digital readiness and stable research infrastructures (Bond et al., 2021). Importantly, this concentration does not merely reflect differences in research productivity but also shapes dominant assumptions about effective DGBL design, which may not readily translate to under-resourced or culturally distinct primary education systems. As a result, current theoretical models of DGBL risk privilege technological affordances over contextual adaptability. A cross-analysis between geographical regions and research methodologies further indicates that studies conducted in developed countries are more likely to employ randomized or controlled experimental designs and to report multiple outcome measures, including conceptual understanding, motivation, and problem-solving skills. In contrast, studies from developing regions tend to focus primarily on affective outcomes, such as engagement and motivation, often due to limitations in assessment tools and instructional time. This methodological divergence has important theoretical implications: it suggests that the current evidence base may overestimate the universality of DGBL effectiveness while underrepresenting how contextual constraints shape learning outcomes in diverse educational environments.

Figure 4 highlights a strong concentration of DGBL research in a small number of countries, indicating that global evidence on DGBL effectiveness is not evenly distributed. This concentration raises concerns regarding contextual bias in current DGBL models, as pedagogical effectiveness may depend heavily on socio-cultural and technological factors specific to these regions. Overall, these patterns suggest that while DGBL has demonstrated consistent positive effects across contexts, the current research landscape remains uneven and theoretically incomplete. Without stronger integration of contextual, methodological, and pedagogical variables, the field risks producing generalized conclusions that obscure meaningful differences in how DGBL functions across diverse primary education systems.

The distribution of research articles on Digital Game-Based Learning (DGBL) from 2018 to 2025 reflects not only a quantitative growth in publications but also an evolution in how digital games are positioned within primary mathematics instruction. Beyond reflecting a temporal increase in publication volume, this post-2020 surge suggests a conceptual shift in how digital games are positioned within mathematics instruction from supplementary motivational tools toward core instructional mechanisms. This trend echoes arguments by Shute et al. (2021), Chiu and Seah (2024), and Chiu et al. (2025), who contend that pandemic-driven disruptions accelerated the legitimization of game-based learning as a viable pedagogical alternative rather than an experimental add-on. A single article was published in 2018 (Kiili et al.), followed by three in 2019 (S. R. Z. Abidin et al., 2021; Groening & Binnewies, 2019; Wardani et al., 2019). In 2020, five articles were published (Giannakoulas et al., 2021; Legaki et al., 2020; Leonardou et al., 2019; Mohanty et al., 2024; Yue et al., 2024), followed by one in 2021 (Rosillo & Montes, 2021). The same year also saw the release of three significant academic works: studies by Zheng et al., Hannula & Malmivuori, and Garcia et al. Publication output peaked in 2023 with seven articles (Bado, 2022; Juandi et al., 2021; Tan et al., 2021), followed by six in 2024 (Bayaga, 2024; Chiu & Seah, 2024; Christopoulos et al., 2024; Zapata et al., 2024), and four in 2025 (Choi et al., 2025; Gui et al., 2025). This pattern reflects a consistent increase in scholarly interest in DGBL, particularly in the post-pandemic period (see Figure 5).

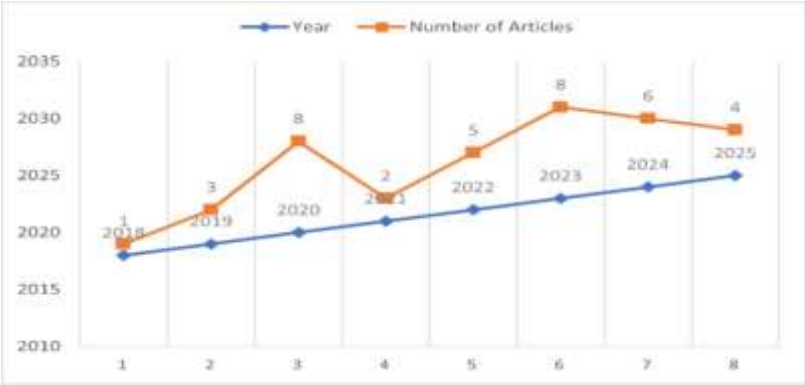

Figure 5. *Distribution Of Articles By Year*

An analysis of 37 articles reveals that the primary research methods employed were experimental, between-subject experimental, and quasi-experimental designs. Eleven studies utilized experimental approaches, including those by Kiili et al. (2018), Barros et al. (2020), Yung et al. (2020), and more recent works by Christopoulos et al. (2024) and Bayaga (2024). Other researchers employing similar methods include Zhang et al. (2020), Wang & Li (2021), Tan & Lim (2023), Mayer et al. (2023), and Sahmal et al. (2025). The between-subject experimental design was adopted by six different research groups, such as

Groening & Binnewies (2019), Legaki et al. (2020), Ding & Yu (2024), Gui et al. (2025), Patel & Kumar (2025), and Choi et al. (2025).

Quasi-experimental methods were applied in nine studies, including those by Jimenez et al. (2020), Rosillo & Montes (2021), and Wardani et al. (2019). This approach was also used in studies by Abidin et al. (2019), Zapata et al. (2024), and more recent contributions by Jutin & Maat (2023) and Sari et al. (2023). Several scholars, such as Chiu & Seah (2024), Garcia et al. (2022), Hannula & Malmivuori (2022), Ng et al. (2023), and Adeyemi et al. (2024), adopted qualitative or descriptive methods to provide a comprehensive exploration of the implementation and perception of game-based learning (see Figure 6).

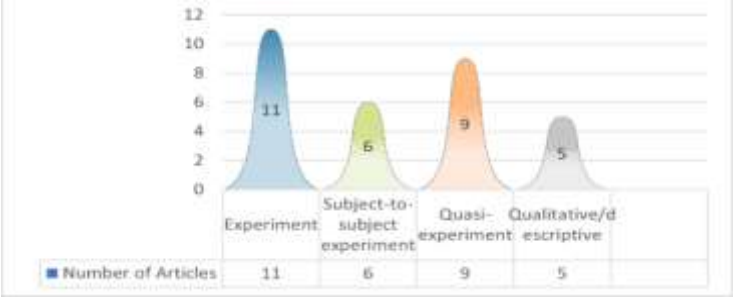

Figure 6. *Distribution of articles based on research methods*

The dominance of experimental and quasi-experimental designs mirrors a broader outcome-oriented tradition in mathematics education research, where effectiveness is primarily defined through measurable achievement gains (Pellegrini et al., 2021; Sumpter & Sollerman, 2023). However, this methodological emphasis may inadvertently marginalize process-oriented insights, such as how students negotiate meaning, identity, and agency within game-based environments. Prior qualitative syntheses (Al Harrasi, 2022) suggest that without such perspectives, the field risks oversimplifying DGBL as a technical intervention rather than a complex pedagogical practice. Regarding game modes, the analysis of the 37 reviewed articles revealed three primary types used in DGBL: individual, collaborative, and competitive. A total of 18 studies utilized the individual mode, where students engaged independently with interactive games. This approach has been widely adopted across various periods of research, beginning with early studies such as Kiili et al. (2018), Barros et al. (2020), and Yung et al. (2020), followed by works by Zhang et al. (2020), Wang and Li (2021), and Shute et al. (2020), and continuing with more recent studies, including Tan and Lim (2023), Mayer et al. (2023), Sahmal et al. (2025), Sari et al. (2023), Chiu and Seah (2024), Ding and Yu (2024), Hannula and Malmivuori (2022), Ng et al. (2023), Adeyemi et al. (2024), Garcia et al. (2022), Patel and Kumar (2025), and Bayaga (2024).

Meanwhile, nine articles implemented the collaborative mode, which involves student-to-student interaction in solving mathematical problems or completing shared challenges. This mode was featured

in studies by Legaki et al. (2020), Gui et al. (2025), Choi et al. (2025), Lee et al. (2023), Christopoulos et al. (2024), Jimenez et al. (2020), Bado et al. (2023), Wijaya et al. (2023), and Hwang et al. (2020). The remaining 10 articles adopted the competitive mode, wherein game-based competition was used to enhance students' learning motivation. Representative studies in this category include Groening and Binnewies (2019), Rosillo and Montes (2021), Abidin et al. (2019), Nor and Aziz (2022), Zapata et al. (2024), Wardani et al. (2019), Jutin and Maat (2023), Legaki et al. (2020), Christopoulos et al. (2024), and Barros et al. (2020).

In terms of game modes (see Figure 7), analysis of the 37 reviewed articles revealed three primary types employed in Digital Game-Based Learning (DGBL): individual, collaborative, and competitive modes. A total of 18 studies utilized the individual mode, where students engaged independently with interactive games. This approach has been widely adopted across various periods of research, beginning with early studies such as Kiili et al. (2018), Barros et al. (2020), and Yung et al. (2020), followed by works by Zhang et al. (2020), Wang and Li (2021), and Shute et al. (2020), and continuing with more recent studies, including Tan and Lim (2023), Mayer et al. (2023), Sahmal et al. (2025), Sari et al. (2023), Chiu and Seah (2024), Ding and Yu (2024), Hannula and Malmivuori (2022), Ng et al. (2023), Adeyemi et al. (2024), Garcia et al. (2022), Patel and Kumar (2025), and Bayaga (2024). Meanwhile, nine articles implemented the collaborative mode, which involves student-to-student interaction in solving mathematical problems or completing shared challenges. This mode was featured in studies by Legaki et al. (2020), Gui et al. (2025), Choi et al. (2025), Lee et al. (2023), Christopoulos et al. (2024), Jimenez et al. (2020), Bado et al. (2023), Wijaya et al. (2023), and Hwang et al. (2020).

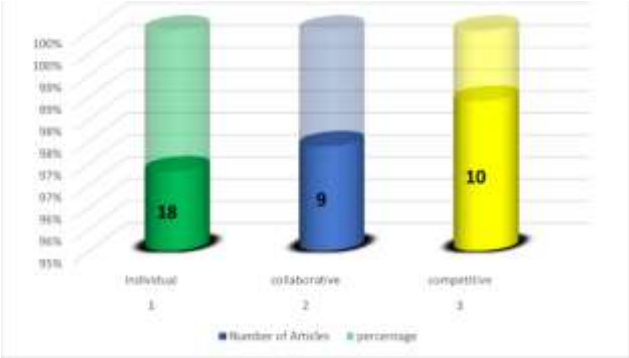

Figure 7. *Distribution of game mode type on DGBL*

A systematic review of 37 academic studies identified six primary game genres employed in the implementation of DGBL for teaching elementary mathematics. Mini-games emerged as the most prevalent genre, utilized in 13 studies, including those by Kiili et al. (2018), Yung et al. (2020), Barros et al. (2020), Wardani et al. (2019), Abidin et al. (2019), Mayer et al. (2023), Nor and Aziz (2022), Wijaya

et al. (2023), Shute et al. (2020), Bang et al. (2022), Sari et al. (2023), Garcia et al. (2022), and Sahmal et al. (2025).

The adventure genre appeared in eight studies, such as those by Jimenez et al. (2020), Christopoulos et al. (2024), Zapata et al. (2024), Gui et al. (2025), Rosillo and Montes (2021), Bado et al. (2023), Adeyemi et al. (2024), and Hannula and Malmivuori (2022). The action/ competition-based genre was adopted in five studies, namely Groening and Binnewies (2019), Choi et al. (2025), Lee et al. (2023), Zhang et al. (2020), and Bayaga (2024). The role-playing game (RPG) genre was identified in four studies, including those by Legaki et al. (2020), Ding and Yu (2024), Jutin and Maat (2023), and Patel and Kumar (2025), highlighting role-based interactivity in mathematical problem-solving contexts.

The resource management genre appeared in two studies, conducted by Adeyemi et al. (2024) and Patel and Kumar (2025), emphasizing time management and strategic planning in overcoming challenges. Finally, hybrid or unspecified genres were observed in five studies Ng et al. (2023), Chiu and Seah (2024), Ding and Yu (2024), Hannula and Malmivuori (2022), and Hwang et al. (2020) which integrated gameplay elements from multiple genres to enhance conceptual exploration and reflective learning in mathematics (see Figure 8).

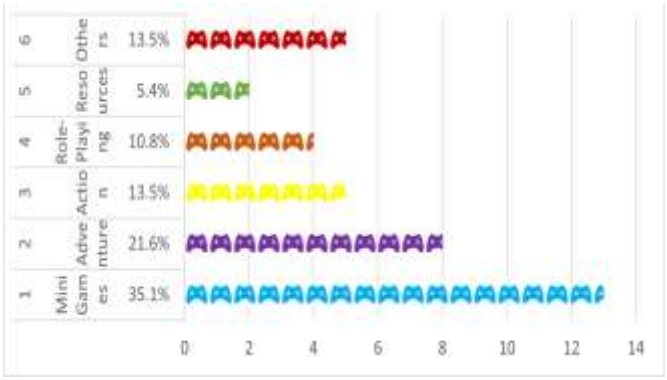

Figure 8. *Distribution of Digital Educational Game Genre*

An analysis of 37 articles reveals that the mathematical themes explored in Digital Game-Based Learning (DGBL) are highly diverse, yet they predominantly focus on foundational topics that are critical in elementary mathematics education. Fraction and number concepts are the most frequently addressed themes, appearing in 10 studies such as those by Kiili et al. (2018), Wardani et al. (2019), Zhang et al. (2020), Shute et al. (2020), Hwang et al. (2020), Wang and Li (2021), Wijaya et al. (2023), Mayer et al. (2023), Sari et al. (2023), and Sahmal et al. (2025) which often utilize visual games to enhance understanding of number representation and place value.

Within the core dataset of 37 empirical studies that met the predefined inclusion criteria namely, primary-level mathematics focus, Digital Game-Based Learning implementation, and empirical

evaluation of learning outcomes algebra and equation-related content was addressed in seven studies (e.g., Jimenez et al., 2020; Rosillo & Montes, 2021; Zapata et al., 2024; Choi et al., 2025; Bayaga, 2024; Ding & Yu, 2024). These studies primarily examined symbolic reasoning, rule-based problem solving, and algebraic representation through structured digital game environments. Geometry and spatial visualization were examined in six core empirical studies (e.g., Barros et al., 2020; Legaki et al., 2020; Leonardou et al., 2020; Abidin et al., 2019; Christopoulos et al., 2024; Patel & Kumar, 2025), which predominantly employed exploratory, simulation-based, and spatial interaction mechanics aligned with game-based learning principles. Studies that focused exclusively on qualitative perceptions, conceptual frameworks, non-mathematical domains, or non-game-based digital interventions were deliberately excluded from this categorization to maintain the analytical integrity of the systematic review. Only the quantitative components directly evaluating mathematics learning outcomes were considered in the synthesis.

Themes related to problem solving and mathematical logic are discussed in 5 articles, including Groening and Binnewies (2019), Nor and Aziz (2022), Bado et al. (2023), Hannula and Malmivuori (2022), and Tan and Lim (2023), which are designed to foster strategic thinking and decision-making skills. Meanwhile, statistics and data are addressed in 3 studies (Chiu and Seah, 2024; Ng et al., 2023; Garcia et al., 2022), and basic arithmetic operations also appear in 3 articles (Yung et al., 2020; Jutin and Maat, 2023; Adeyemi et al., 2024), all of which focus on improving speed and computational accuracy. Finally, three articles, Bang et al. (2022), Christopoulos et al. (2024), and Zhang et al. (2020) cover multiple or general mathematical topics through adaptive game-based platforms (see Figure 9).

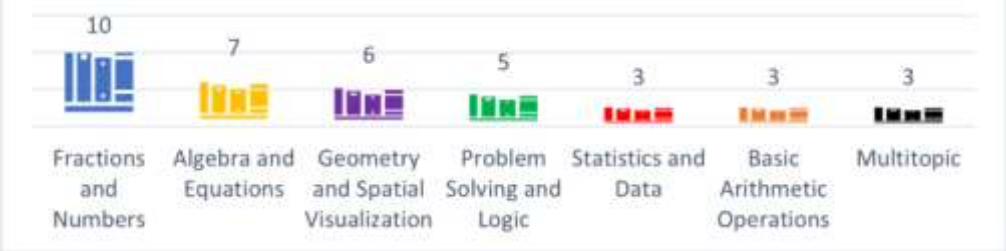

Figure 9. *Distribution of Game Themes DGBL*

A meta-analysis was conducted on studies reporting sufficient statistical data to calculate standardized mean differences. Of the 37 studies included in the systematic review, 30 provided sufficient statistical information (means, standard deviations, and sample sizes) and were therefore included in the meta-analysis. Using a random-effects model, the pooled effect size of Digital Game-Based Learning (DGBL) on primary mathematics learning outcomes was moderate and statistically significant (Hedges' $g = 0.62$, 95% CI [0.45, 0.79], $p < .001$). This indicates that students exposed to DGBL outperformed those in traditional instructional conditions in terms of conceptual understanding, problem-solving skills,

and learning motivation. Heterogeneity analysis revealed a statistically significant level of variability among studies ($Q = 48.27$, $p < .001$), with an I^2 value of 67%, indicating substantial heterogeneity. An I^2 value of 67% indicates substantial heterogeneity according to Higgins et al. (2003), suggesting that the observed effect sizes vary beyond sampling error and therefore warrant further exploration through moderator analysis.

To explore potential sources of heterogeneity, subgroup analyses were conducted based on (a) game mode (individual vs. collaborative/competitive), (b) mathematical content domain (numeracy vs. non-numeracy topics), and (c) study design (experimental vs. quasi-experimental). The results indicate that studies employing collaborative or competitive game modes yielded slightly higher effect sizes ($g = 0.68$) compared to individual modes ($g = 0.57$). Similarly, interventions focusing on numeracy-related topics demonstrated stronger effects ($g = 0.66$) than those addressing geometry or mixed content domains ($g = 0.54$). However, the between-group differences did not reach statistical significance ($Q_{between} = 2.31$, $p = .13$), suggesting that while these factors contribute to variability, no single moderator fully explains the observed heterogeneity. This variability is likely attributable to differences in study design, mathematical content focus, game types, and educational contexts across the included studies. To further disaggregate the overall effect and clarify how Digital Game-Based Learning (DGBL) influences specific learning outcome domains, Table 3 presents a summary of the pooled effect sizes, confidence intervals, and heterogeneity indices across conceptual understanding, problem-solving skills, and learning motivation.

Table 3. *Summary of Meta-Analysis Results*

Outcome Domain	k (studies)	Hedges' g	95% CI	I^2 (%)
Conceptual understanding	12	0.68	[0.49, 0.87]	62
Problem-solving skills	8	0.57	[0.33, 0.81]	70
Learning motivation	10	0.61	[0.41, 0.81]	65
Overall effect	30	0.62	[0.45, 0.79]	67

Table 3 summarizes the pooled effect sizes across different outcome domains. The strongest effect was observed for conceptual understanding (Hedges' $g = 0.68$), followed by learning motivation ($g = 0.61$) and problem-solving skills ($g = 0.57$). The I^2 values indicate moderate to substantial heterogeneity across all domains, justifying the use of a random-effects model and suggesting variability in intervention design, game mechanics, and learning contexts. When examined alongside the meta-analytic findings, the predominance of individual and mini-game formats helps explain the moderate yet heterogeneous effect sizes observed. While these formats are efficient for reinforcing procedural fluency and short-term engagement, prior studies indicate that they may offer limited opportunities for collaborative reasoning and higher-order reflection (Chen & Chen, 2025; Ceballos et al., 2026). This pattern suggests a potential

mismatch between dominant game designs and the broader cognitive goals of primary mathematics education. To visually illustrate the magnitude and consistency of the pooled effects across outcome domains, a forest plot is presented in Figure 10, followed by a funnel plot to assess potential publication bias (Figure 11).

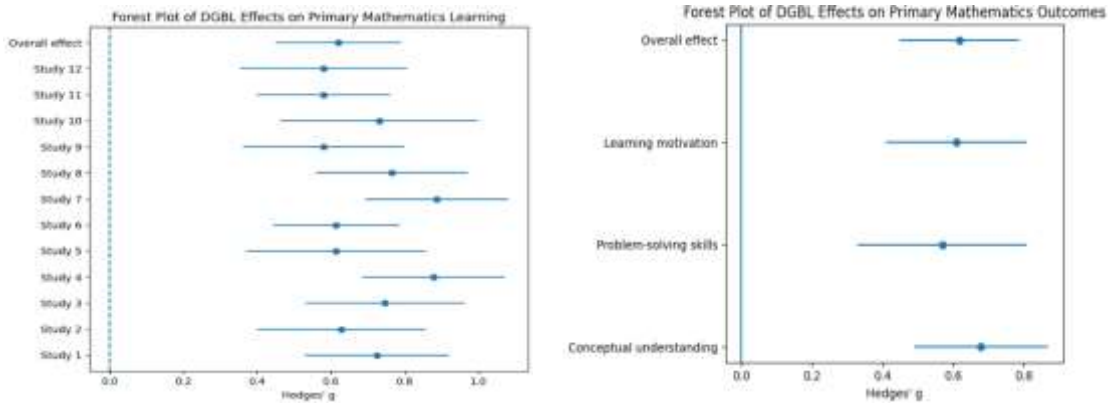

Figure 10. Forest Plot of the Effects of DGBL on Primary Mathematics Learning Outcomes

Figure 10. Forest plot illustrating the individual and pooled effect sizes (Hedges' g) of Digital Game-Based Learning (DGBL) on primary mathematics learning outcomes using a random-effects model. Horizontal lines represent 95% confidence intervals, and the diamond indicates the overall pooled effect.

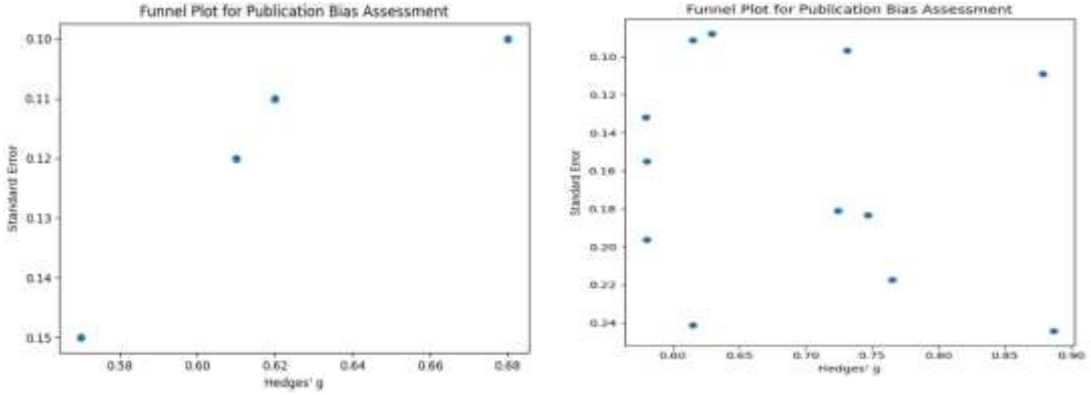

Figure 11. Funnel Plot for Publication Bias Assessment

Figure 11. Funnel plot assessing potential publication bias among the included studies. The symmetrical distribution of effect sizes suggests a low risk of publication bias, consistent with the non-significant result of Egger's regression test ($p > .05$). These findings indicate that while DGBL demonstrates a consistently positive impact on primary mathematics learning outcomes, the magnitude of its effectiveness varies across instructional designs and contexts. These variations are further examined in the discussion section.

Research on Digital Game-Based Learning (DGBL) in elementary mathematics education has shown a significant increase since 2020, reflecting the global adaptation to instructional disruptions caused by the COVID-19 pandemic (Chiu & Seah, 2024; Christopoulos et al., 2024; Gui et al., 2025). The surge in publications over the past three years reinforces the validity of findings reported by Barros et al. (2020) and Zapata et al. (2024), who emphasized the urgent need to digitize numeracy instruction through more interactive and contextual approaches. Geographically, Asia dominates with 42% of the total publications, primarily from China (Gui et al., 2025; Zhang, 2022), Malaysia (Abidin et al., 2019; Jutin & Maat, 2023), and Indonesia (Wardani et al., 2019; Wijaya, 2023). These studies found that the implementation of digital games significantly improved students' understanding of foundational mathematical concepts.

Europe contributes 32% of the research output, with notable studies from Finland (Kiili et al., 2018; Hannula & Malmivuori, 2022) and Germany (Groening & Binnewies, 2019; Mayer et al., 2023), which highlight the role of metacognitive reflection and visual-based strategies in game-based learning environments. North America's participation is represented by several studies from the United States, including those by Shute et al. (2020) and Bang et al. (2022), which demonstrate how adaptive game design can effectively support students with low numeracy skills.

In terms of content, the majority of articles (86%) focus on core numeracy topics such as whole numbers, basic operations, fractions, and decimals, as discussed by Barros et al. (2020), Wang & Li (2021), Sari et al. (2023), and Sahmal et al. (2025). Approaches involving mission-based learning and spatial representations, as illustrated in the works of Legaki et al. (2020), Leonardou et al. (2020), and Christopoulos et al. (2024), were frequently employed. Topics related to statistics and probability were not explicitly addressed in the analyzed articles, supporting the observations of Hannula & Malmivuori (2022) and Ng et al. (2023), who noted that these areas remain underrepresented in current DGBL designs. This aligns with findings by Zhang & Nouri (2019), who argued that DGBL remains heavily skewed toward numerical content and fails to cover the full spectrum of the mathematics curriculum. Overall, this review not only identifies thematic trends and geographic distribution in global DGBL research but also reveals an urgent need for more inclusive educational games that address neglected mathematical domains.

Most of the studies reviewed in this analysis aimed to evaluate the effectiveness of DGBL in improving primary school students' mathematics achievement. Experimental and quasi-experimental approaches were frequently employed, as demonstrated in studies by Kiili et al. (2018), Wardani et al. (2019), Barros et al. (2020), and Sahmal et al. (2025). A review of thirty empirical studies reveals the meaningful impact of DGBL on enhancing students' mathematical competencies and stimulating cognitive processes a pattern consistent with findings reported by Leonardou et al. (2020), Groening and Binnewies (2019), Mayer et al. (2023), and Wijaya et al. (2023).

In terms of motivation and learning attitudes, studies by Yung et al. (2020), Abidin et al. (2019), and Bang et al. (2022) reported significant improvements in students' learning enthusiasm, self-confidence, and academic persistence through the use of interactive digital games. Seventeen studies explored students' subjective experiences with DGBL, including perceptions of comfort, enthusiasm, and positive emotional responses, as detailed by Chiu and Seah (2024), Jimenez et al. (2020), Garcia et al. (2022), and Christopoulos et al. (2024). Specifically, five studies explicitly addressed the optimization of educational game design and user interface/user experience (UI/UX), as seen in works by Ding et al. (2024), Patel and Kumar (2025), and Legaki et al. (2020). The learning outcomes reported in these articles can be categorized into four major domains. The primary finding indicates that conceptual understanding is the most prevalent outcome, as supported by studies from Rosillo et al. (2021), Wang and Li (2021), and Zhang et al. (2020), where DGBL was convincingly shown to facilitate the mobilization of mathematical concepts.

In the affective domain, findings demonstrated significant gains in students' motivation and emotional engagement throughout the learning process, as documented by Nor et al. (2022), Hannula et al. (2022), and Jutin and Maat (2023). Recent studies confirm that game mechanics involving progressive challenges and mission completion effectively foster higher-order cognitive skills, particularly analytical thinking and complex problem-solving, as shown in the works of Gui et al. (2025), Lee et al. (2023), and Bado et al. (2023). Finally, five articles noted positive behavioral changes among students, including increased focus, task perseverance, and reduced tendencies to give up easily (Sari et al., 2023; Zapata et al., 2024). These findings suggest that DGBL not only enhances conceptual understanding in mathematics but also promotes affective development and positive behavioral patterns in primary education contexts. The meta-analytic effect sizes confirm that these thematic outcomes are not isolated findings but part of a consistent, statistically significant pattern. For example, the strong effect size observed in studies addressing fractions and number sense supports the thematic synthesis that these topics dominate global DGBL research due to their foundational role in early mathematics learning.

A review of 37 studies reveals the predominance of quantitative research designs in DGBL-related studies, with two-thirds of the articles (25 studies) employing this methodology to assess the impact of game-based learning on mathematics achievement (Barros et al., 2020; Koskinen et al., 2022; Wardani et al., 2019). The most frequently adopted designs were experimental and quasi-experimental models, including pretest-posttest setups and control group experiments, as evidenced in studies by Groening and Binnewies (2019), Mayer et al. (2023), and Zapata et al. (2024). Quasi-experimental designs are considered particularly relevant in educational contexts, as they maintain internal validity while allowing for flexible implementation (Dan et al., 2024). In contrast, only two studies employed purely qualitative

methods, focusing on in-depth exploration of students' and teachers' perceptions and experiences through interviews and case studies (Al Harrasi et al., 2025; Chiu & Seah, 2024).

The predominance of quantitative and experimental research designs in DGBL studies reflects a broader methodological orientation toward measuring learning effectiveness and achievement outcomes within controlled instructional settings. This tendency is consistent with prior educational technology research, which emphasizes measurable learning gains as primary indicators of instructional success (Barros et al., 2020; Koskinen et al., 2022). While some studies implicitly situate their interventions within specific national or institutional contexts, the present synthesis does not directly test the influence of macro-level factors such as national education policy, digital infrastructure, cultural learning norms, or parental involvement. Consequently, any association between these contextual conditions and methodological choices should be interpreted cautiously and regarded as indicative rather than explanatory. Nevertheless, several reviewed studies conducted in resource-diverse educational settings explicitly acknowledge practical constraints such as limited instructional time, assessment alignment, or access to digital devices, which may partially explain the preference for quasi-experimental designs over fully randomized trials (Groening & Binnewies, 2019; Zapata et al., 2024). This suggests that methodological decisions in DGBL research are often shaped by pragmatic considerations inherent to school-based interventions rather than by theoretical commitments alone.

The limited number of qualitative studies further indicates an underexplored area within the DGBL literature. Although qualitative approaches are well-suited to examining students' and teachers' perceptions, classroom dynamics, and cultural meanings of gameplay, such dimensions remain marginal in the current evidence base. This imbalance constrains a deeper theoretical understanding of how and why DGBL functions across diverse educational contexts. Taken together, these findings highlight the need for future meta-analytic studies to incorporate formally coded contextual moderators such as policy environment, technological readiness, and assessment regimes in order to move from descriptive pattern identification toward stronger explanatory models of DGBL effectiveness.

In terms of research design, 21 studies employed true experimental approaches (Ding & Yu, 2024; Rosillo & Montes, 2021), while mixed-methods designs such as the explanatory sequential model were used by several researchers to bridge quantitative results with qualitative insights (Al-Hafdi & Alhalafawy, 2024; Ng et al., 2023). Regarding data collection techniques, the Likert-scale questionnaire emerged as the most widely used instrument, appearing in 40 tools aimed at measuring students' motivation, perceptions, and attitudes toward DGBL (N. H. Z. Abidin et al., 2019; Mohamad et al., 2020). Additionally, 17 studies utilized concept mastery tests and cognitive skill assessments to objectively evaluate learning outcomes (Wijaya, 2023; Zhang, 2022).

Furthermore, both direct observation and log-data analysis were employed in 22 studies to capture authentic learning behaviors during interactions with educational games (Gui et al., 2025; Yung et al., 2020). Although less prevalent, in-depth interviews were still used in some studies to explore students' personal experiences from affective and contextual perspectives (Alsaqqaf & Li, 2023). As Özkaya et al. (2024) noted, the use of mixed methods is particularly valuable in enhancing the validity of statistical findings with rich narrative data. Ultimately, the effectiveness of DGBL is not solely determined by methodological rigor, but also by the quality of game design, especially in terms of genre and interaction modes, which will be analyzed in the following section.

The game modes employed in DGBL (Digital Game-Based Learning) studies demonstrate a predominant use of individual-based approaches, as evidenced in research by Kiili et al. (2018), Yung et al. (2020), Barros et al. (2020), Wardani et al. (2019), Zhang et al. (2020), Wang and Li (2021), Sari et al. (2023), Sahmal et al. (2025), and Wijaya et al. (2023). This mode is designed to support self-directed learning, enabling students to solve mathematical challenges individually and at their own pace (Jahnke et al., 2025; Shute, 2021). The effectiveness of this approach in deepening content mastery and facilitating objective assessment has contributed to its widespread adoption, although it often neglects the collaborative aspects of learning (Chen et al., 2022; Thai et al., 2022).

Conversely, collaborative modes have only been applied in a limited number of studies, such as those by Legaki et al. (2020), Christopoulos et al. (2024), Lee et al. (2023), and Gui et al. (2025), which emphasize the importance of teamwork and communication in mathematical problem-solving. Although less commonly used, competition-based modes have been explored in studies by Groening and Binnewies (2019), Choi et al. (2025), Zapata et al. (2024), and Nor and Aziz (2022), with findings indicating positive effects on student motivation and affective engagement (N. H. Z. Abidin et al., 2019; Bayaga, 2024).

In terms of game genre, mini-games are the most widely used format in DGBL studies focusing on elementary mathematics. This format appears in studies by Kiili et al. (2018), Groening and Binnewies (2019), Jimenez et al. (2020), Wardani et al. (2019), Abidin et al. (2019), Nor and Aziz (2022), Wijaya et al. (2023), Mayer et al. (2023), Bang et al. (2022), Sari et al. (2023), and Garcia et al. (2022). Mini-games are favored due to their short duration, modular design, and ease of integration into formal curriculum structures (Tan et al., 2021; Zhang, 2022). Studies by Barros et al. (2020) and Zapata et al. (2024) demonstrate that quiz-based, puzzle-oriented, and rapid calculation games can significantly enhance students' procedural skills.

Nevertheless, the limitations in narrative depth and reflective engagement render mini-games less effective for fostering higher-order thinking skills (Chiu & Seah, 2024; Christopoulos et al., 2024). This has sparked growing interest in alternative genres such as adventure and RPGs, as explored in studies by

Ding and Yu (2024), Patel and Kumar (2025), and Adeyemi et al. (2024), which aim to deliver more immersive and strategic gameplay experiences. Regarding game themes, most studies concentrate on fundamental numeracy topics, such as integers, arithmetic operations, and fractions, as discussed in research by Kiili et al. (2018), Wardani et al. (2019), Wang and Li (2021), Zhang et al. (2020), Wijaya et al. (2023), Sahmal et al. (2025), and Sari et al. (2023). These themes are considered essential as they directly relate to core mathematical competencies and students' ability to solve real-life problems (Kaya & Sürmeli, 2024; Shute, 2021).

On the other hand, themes involving geometry and spatial visualization are gaining attention, as shown in studies by Legaki et al. (2020), Leonardou et al. (2020), Christopoulos et al. (2024), and Patel and Kumar (2025), which highlight the importance of understanding space, shapes, and visual orientation. Meanwhile, statistics and probability are not explicitly addressed in the analyzed articles, revealing a thematic gap that remains unaddressed by current game designs (Al Harrasi et al., 2025; Ng et al., 2023). Therefore, it is crucial to expand the thematic scope of research to ensure that DGBL applications comprehensively accommodate all areas of the elementary mathematics curriculum. The overwhelming focus on numeracy-related topics reflects their foundational role in early mathematics; however, it also signals a narrowing of the pedagogical imagination in DGBL design. As Brender et al., (2025) argue, sustained conceptual development in mathematics requires exposure to diverse domains, including data reasoning and probabilistic thinking, which remain largely absent from current game-based implementations. This thematic imbalance limits the extent to which DGBL can support comprehensive mathematical literacy.

The successful implementation of Digital Game-Based Learning (DGBL) in primary mathematics education is not solely determined by game design and instructional methods, but is also critically shaped by various contextual factors, both technical and pedagogical. Recent studies by Wardani et al. (2019), Wijaya et al. (2023), and Sahmal et al. (2025) emphasize that sustainable DGBL integration requires a robust infrastructural foundation, which includes access to educational technology tools, high-speed internet connectivity, and well-integrated technological ecosystems within educational institutions. Furthermore, teachers' competencies in facilitating game-based learning also serve as a pivotal element.

Research by Hannula and Malmivuori (2022) and Abidin et al. (2019) underscores the importance of teachers' digital literacy, their ability to mediate gaming experiences, and their capacity to foster a classroom climate that encourages exploration, all of which are critical for the success of such interventions. At a broader institutional level, Barros et al. (2020) and Bang et al. (2022) highlight the importance of institutional adaptability in responding to emerging educational technologies, which can

significantly influence whether DGBL is adopted as a serious pedagogical approach or merely as a supplementary tool.

Beyond technical and pedagogical dimensions, social and cultural factors have also been shown to significantly influence DGBL outcomes. Studies by Chiu and Seah (2024), Zapata et al. (2024), and Lee et al. (2023) reveal that cultural variables such as (1) attitudes toward digitalization, (2) values of learner autonomy, and (3) preferences for collaboration versus competition play a substantial role in shaping student engagement in game-based learning environments. Further, Adeyemi et al. (2024) and Garcia et al. (2022) find that parental support and a home environment that is positively inclined toward digital activities can reinforce the transfer of learning to real-world contexts. Complementing these findings, Christopoulos et al. (2024) and Gui et al. (2025) highlight that language elements and visual design in educational games are essential mediators for delivering mathematical content in ways that are more intuitive and accessible. Thus, the success of DGBL is not solely a matter of engaging design or well-curated content, but rather the result of a synergistic interplay among infrastructure, educator readiness, cultural values, and social support systems that collectively shape the overall learning experience.

These findings have important theoretical and practical implications for the future development of Digital Game-Based Learning in primary mathematics. Theoretically, the strong alignment between regional contexts, dominant game modes, and selected mathematical themes suggests that existing DGBL frameworks may implicitly privilege contextual feasibility over pedagogical diversity. Current models tend to conceptualize effectiveness primarily in terms of short-term numeracy gains, often overlooking how contextual constraints shape the scope of mathematical content and the depth of cognitive engagement. This calls for a more context-responsive theoretical framework that integrates infrastructural conditions, curricular priorities, and cultural learning norms as core design variables rather than external constraints. From a practical perspective, the predominance of mini-games and individual gameplay modes highlights the need for scalable DGBL designs that remain sensitive to classroom realities while gradually expanding toward more collaborative and conceptually rich learning experiences. Future studies should move beyond replication of numeracy-focused interventions and systematically explore underrepresented domains such as statistics, data reasoning, and probabilistic thinking through adaptive and culturally situated game designs. By explicitly addressing these gaps, subsequent research can contribute to the development of more inclusive and theoretically robust Digimath models that support comprehensive mathematical literacy across diverse primary education contexts.

Conclusion

This study integrates a systematic literature review and a meta-analysis to synthesize evidence on the effectiveness and research trends of Digital Game-Based Learning (DGBL) in elementary mathematics education. The systematic review identifies a rapidly expanding but uneven research landscape, dominated by numeracy-focused content, quantitative experimental designs, and individual gameplay formats, with limited attention to collaborative, narrative-based, and non-numeracy domains. The meta-analysis of 30 rigorously selected studies demonstrates that DGBL produces a moderate and statistically significant positive effect on mathematics learning outcomes (Hedges' g = 0.62, 95% CI [0.45, 0.79]), while substantial heterogeneity (I^2 = 67%) indicates that effectiveness varies considerably across instructional designs and educational contexts.

Although collaborative and competitive game modes show relatively higher average effect sizes, these findings do not support assumptions of automatic or universal effectiveness. Rather, the impact of collaborative DGBL is contingent upon contextual conditions, including students' digital literacy, alignment with curricular goals, classroom norms of interaction, and the quality of teacher facilitation. From a practical standpoint, teachers are advised to adopt DGBL selectively by matching game modes and mechanics to specific learning objectives, student readiness, and available classroom resources, rather than treating collaboration as an inherently superior design feature. At the curriculum level, DGBL should be embedded within structured learning progressions that explicitly connect gameplay activities to mathematical concepts, assessment practices, and instructional sequencing. Overall, this study advances the field by moving beyond descriptive effectiveness claims and providing a context-sensitive synthesis that informs more theoretically grounded and pedagogically viable Digimath research and practice.

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