Original Research Article

The Efficacy of Gamification in Mathematics Education: A Quantitative Synthesis of its Effects on Student Engagement and Achievement

Abstract

This paper investigates the influence of gamification on student engagement and objective learning outcomes in mathematics across diverse educational institutions. It begins by analysing current literature to establish a robust definition of gamification, differentiating it clearly from Game-Based Learning (GBL) and grounding its efficacy in established behavioral and cognitive frameworks, including Self-Determination Theory, Cognitive Load Theory, and Constructivist Pedagogy. A rigorous quantitative meta-analysis was conducted, consolidating evidence from 54 empirical studies that examined gamification's effects on mathematics learning outcomes. The random-effects model applied yielded a statistically significant overall effect size of g=0.66 (with a 95% confidence interval of [0.46,0.85]), indicating a moderate to large positive effect compared to traditional teaching methods. While the primary findings confirm that gamification is broadly beneficial and has the capacity to strengthen student performance in mathematics, the study also highlights critical implementation challenges. These include the risks associated with over-relying on extrinsic motivation, the difficulty of designing systems that accurately represent complex mathematical concepts and the currently underdeveloped research area concerning teacher competency for successful integration. Consequently, this research provides evidence-based recommendations for educators, curriculum designers and policymakers on strategic approaches to fully and sustainably leverage gamification's potential within mathematics education.

Keywords: Gamification; Mathematics; Education; Meta-analysis

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16

1 Introduction

The landscape of 21st-century education demands pedagogical innovation to meet the diverse needs of students in an increasingly technology driven world. Despite the critical importance of quantitative

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literacy for economic and civic participation, mathematics education globally continues to face constant challenges, notably characterised by low student engagement and high rates of mathematics anxiety (1; 2). Traditional, instructional models often fail to foster the necessary intrinsic motivation required for students to struggle with abstract mathematical concepts (3). This conceptual difficulty, which places a significant burden on cognitive resources, often leads to passive learning, avoidance behaviors and ultimately, suboptimal academic performance (4). Consequently, there is an urgent need to investigate and adopt novel, empirically validated interventions that can enhance student motivation and improve objective learning outcomes.

In response to these challenges, gamification has emerged as a promising pedagogical strategy. Gamification is defined as the utilisation of game design elements, such as points, badges, leaderboards, narratives and progress bars in non-game contexts, within the classroom (5). The initial theoretical appeal of this approach lies in its potential to harness the psychological mechanisms that drive engagement in games and apply them to academic tasks. By offering clear goals, immediate feedback and opportunities for iterative failure and success, gamification promises to increase student motivation, promote deeper cognitive processing and foster a more positive affective domain towards mathematics (6).

To ensure the precision necessary for scholarly analysis, this study maintains a crucial distinction between gamification and Game-Based Learning (GBL). While GBL involves the use of complete, pre-built educational games (such as dedicated simulation software or virtual reality experiences), gamification focuses on applying elements of game design to an existing curriculum or task structure. This paper focuses specifically on gamification, as its mechanics are highly adaptable and scalable across various curriculum frameworks and institutional settings, from primary schools to higher education, making it a more flexible and widespread intervention for mathematics instructors (7).

The efficacy of gamification in an educational context is grounded in well-established psychological and pedagogical theories. Specifically, this paper uses three core frameworks to interpret the intervention's mechanisms:

- Self-Determination Theory (SDT): Gamified environments are hypothesised to satisfy the basic psychological needs articulated by SDT: Autonomy (by offering choice in tasks or pathways), Competence (through clear level progression and achievement badges) and Relatedness (via team-based challenges or leaderboards) (8). Satisfying these needs fosters greater intrinsic motivation, which is vital for deep learning.
- Cognitive Load Theory (CLT): Well-designed gamified systems can manage a student's cognitive load by externalising progress, structuring complex concepts into manageable 'levels,' and ensuring feedback is delivered immediately and efficiently (9). This can reduce extraneous cognitive load, allowing more resources to be dedicated to learning the mathematical concepts (germane load).
- Constructivist Pedagogy: Gamification, by encouraging active participation, exploration, and problem-solving within a structured system, aligns with constructivist principles (10). Students construct knowledge actively by engaging with the gamified tasks, rather than passively receiving information.

Despite the strong theoretical backing and a growing number of empirical studies exploring gamification in mathematics education, the collective evidence remains mixed. Individual studies often report varying effect sizes due to differences in sample size, educational context, methodology and the specific game elements employed. Consequently, the field lacks a definitive, large-scale quantitative synthesis to comprehensively evaluate the intervention's true impact.

This study addresses a critical and vital gap in the current body of research by conducting a methodologically rigorous meta-analysis. The need is twofold: first, to move beyond qualitative reviews and anecdotes by statistically aggregating results to calculate a robust, overall mean effect size; and second, to systematically explore sources of heterogeneity and potential moderator variables (such as student age or the duration of the intervention) that influence the effectiveness of gamification across varied institutions and populations.

The primary purpose of this research is to rigorously evaluate the effect of gamification on student learning outcomes in mathematics. This meta-analysis seeks to achieve the specific objectives, to systematically review and synthesise the current empirical evidence regarding gamification's effects on objective mathematics learning outcomes, to quantitatively determine the overall mean effect size of gamification when compared to traditional instructional approaches across diverse educational settings, to explore potential sources of heterogeneity, implementation challenges and contextual factors identified across the consolidated literature and to provide evidence-based, actionable recommendations for educators, curriculum designers and policymakers for the effective and ethical integration of gamification in mathematics instruction.

This paper is structured as follows. Section 2 provides a detailed literature review of the theoretical frameworks underpinning the study, namely Self-Determination Theory (SDT), Cognitive Load Theory (CLT), and Constructivism, as well as an overview of previous meta-analytic research in the field. Section 3 outlines the materials and methods, describing the literature search strategy, inclusion criteria, coding procedures and the random-effects model employed in the analysis. Section 4 presents the results and discussion, including the overall effect size and the analysis of heterogeneity. This part also offers a comprehensive discussion of the findings and their implications. Finally, Section 6 concludes the paper by summarising the key insights and suggesting directions for future research.

2 Literature Review

2.1 Conceptual Foundations and Defining the Scope

Gamification, at its core, involves the strategic application of game design elements and principles to non-game contexts, specifically to increase motivation and engagement (11). These elements typically include visual representations of progress, such as points, badges, leaderboards (PBL), as well as narrative immersion, customised avatars and the provision of immediate, structured feedback (5; 11). The objective in an educational setting is not simply to entertain, but to leverage the inherent psychological drive associated with gaming to promote productive behaviors, such such as focused effort, persistence through failure and skill mastery in the learning environment (6).

2.2 Distinction from Game-Based Learning (GBL)

A crucial step in evaluating the efficacy of gamification is maintaining a clear conceptual boundary between it and Game-Based Learning (GBL). GBL involves the use of complete, self-contained educational games, simulations, or virtual worlds where the learning content is embedded within the rules and mechanics of the game itself (e.g., using a dedicated software simulation to teach physics principles). Conversely, gamification acts as an overlay on an existing, non-game curriculum (7). For example, turning a standard set of math homework problems into a ”quest” with ”XP” for completion is gamification, whereas using a commercial math puzzle game is GBL. This meta-analysis is strictly focused on the impact of gamification, as it represents a highly adaptable instructional modification that can be applied to any existing mathematics curriculum.

2.3 Theoretical Frameworks of Efficacy

The successful integration of game mechanics into education is underpinned by their capacity to satisfy fundamental psychological needs and manage cognitive processes, as detailed by the following frameworks:

2.3.1 Self-Determination Theory (SDT)

SDT posits that human motivation is significantly influenced by the fulfillment of three basic psychological needs: Autonomy, Competence, and Relatedness (12). Gamified systems directly address these needs, thereby fostering greater intrinsic motivation: Competence: Clear levels, skill trees, and instant performance feedback (e.g., scoring points) provide tangible evidence of progression and mastery. Autonomy: Allowing students to choose between different 'quests,' select reward paths, or set individualised goals within the gamified structure grants them a sense of control over their learning journey. Relatedness: Team-based challenges, cooperative tasks, and communal leaderboards facilitate social interaction and a sense of belonging among peers. The shift from controlling, extrinsic rewards to rewards that support these psychological needs is paramount for ensuring that gamification contributes to sustained, deep learning rather than superficial engagement.

2.3.2 Cognitive Load Theory (CLT)

Cognitive Load Theory (CLT) posits that learning is most effective when instructional methods are designed to manage the limited capacity of working memory (9). According to the theory, cognitive load can be classified into three types: intrinsic, extraneous, and germane. Intrinsic load refers to the inherent complexity of the material being learned, such as the difficulty involved in understanding abstract mathematical proofs. Extraneous load arises from poorly designed instructional methods that do not directly contribute to learning, while germane load represents the cognitive effort invested in constructing and refining mental schemas.

When effectively integrated into educational practice, gamification can support the principles of CLT by reducing unnecessary cognitive strain and promoting meaningful learning processes. By organising mathematical content into smaller, progressive stages or 'levels', gamification helps to simplify complex tasks and make them more manageable, thereby reducing extraneous load. Additionally, the immediate and structured feedback provided through game mechanics allows learners to identify and correct mistakes in real time. This process not only prevents the development of misconceptions but also encourages the refinement of cognitive schemas, ultimately enhancing the efficiency and depth of learning.

2.3.3 Constructivist Pedagogy

Gamification aligns closely with constructivist principles, as it encourages learners to actively construct knowledge through hands-on, experiential engagement (10). Games are inherently centred on problem-solving, experimentation and continuous interaction, which mirror the processes of discovery and reflection central to constructivist learning. In a gamified mathematics environment, students are encouraged to explore, test hypotheses, and learn from mistakes in a low-stakes setting. This approach allows them to attempt problems freely, experience failure as part of the learning process, and immediately try alternative strategies without the punitive consequences often associated with traditional assessment. Through this cycle of experimentation and active exploration, learners engage deeply with mathematical concepts, manipulating ideas and applying rules to uncover relationships and solutions. Such experiential engagement promotes a richer understanding of mathematical principles and exemplifies the constructivist view that knowledge is actively built rather than passively absorbed.

2.4 Empirical Landscape and Prior Meta-Analytic Findings

Prior narrative and systematic reviews have generally acknowledged the potential of gamification to enhance engagement and motivation in educational contexts (11). However, its reported effect on objective academic outcomes, specifically within the domain of mathematics, has shown considerable variability. While some studies report significant improvements in test scores and subject fluency (13), others report marginal or negligible effects, particularly when the game mechanics poorly integrate with the learning content. This methodological variance and inconsistency in reported effect sizes across varied study designs underscore a critical research gap, namely the lack of a definitive, large-scale quantitative synthesis. To resolve these mixed findings and provide a reliable, consolidated estimate of impact, a robust meta-analysis is warranted to determine the true effect of gamification on mathematics learning.

Furthermore, variations in outcomes may also stem from differences in implementation fidelity, learner characteristics, and the specific game mechanics employed. For instance, interventions emphasising intrinsic motivational elements such as mastery and autonomy tend to yield stronger and more sustainable effects than those relying solely on extrinsic rewards. Contextual factors such as teacher expertise, curriculum alignment and cultural attitudes toward gaming, also play a crucial role in shaping learning outcomes. These nuances highlight the need for a comprehensive meta-analytic investigation that accounts for both pedagogical design and contextual moderators in evaluating gamification's efficacy.

3 Materials and Methods

3.1 Research Design

This study adopted a meta-analytic design to quantitatively synthesise the results of empirical studies that examined the impact of gamification on student engagement and learning outcomes in mathematics education. Meta-analysis was chosen because it allows the integration of findings across multiple independent studies, thereby increasing statistical power and enabling generalisable conclusions regarding the efficacy of gamified instructional strategies.

Both fixed-effect and random-effects statistical models were employed. The fixed-effect model assumes a common true effect size across studies, while the random-effects model allows for variation among studies arising from differences in context, design and population characteristics. Given the heterogeneity among the included studies, the random-effects model was used to report the primary outcomes.

In addition, the study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines to ensure methodological rigour and transparency throughout the review process (14). Effect size extraction, coding, and statistical synthesis were conducted systematically to minimise bias and enhance replicability. This design not only enables the aggregation of quantitative results but also facilitates the identification of moderating variables that explain variations in gamification effectiveness across educational levels and learning contexts. Thus, the chosen research design provides a robust framework for deriving reliable, evidence-based conclusions about the impact of gamification in mathematics education.

3.2 Data Sources and Search Strategy

A comprehensive search was conducted using electronic databases including *Scopus*, *ScienceDirect*, *EBSCOhost*, *IEEE Xplore*, and *Google Scholar*. To minimise publication bias, relevant grey literature such as dissertations and conference papers was also reviewed. The search period covered January 2010 to March 2025.

Search terms combined Boolean operators (`AND`, `OR`) and included the following keywords: `(gamification OR game-based learning OR GBL) AND (mathematics OR maths OR mathematics education) AND (learning OR student engagement OR motivation OR academic achievement).`

All retrieved studies were screened using the PRISMA 2020 guidelines for transparent study selection as shown in Figure 1.

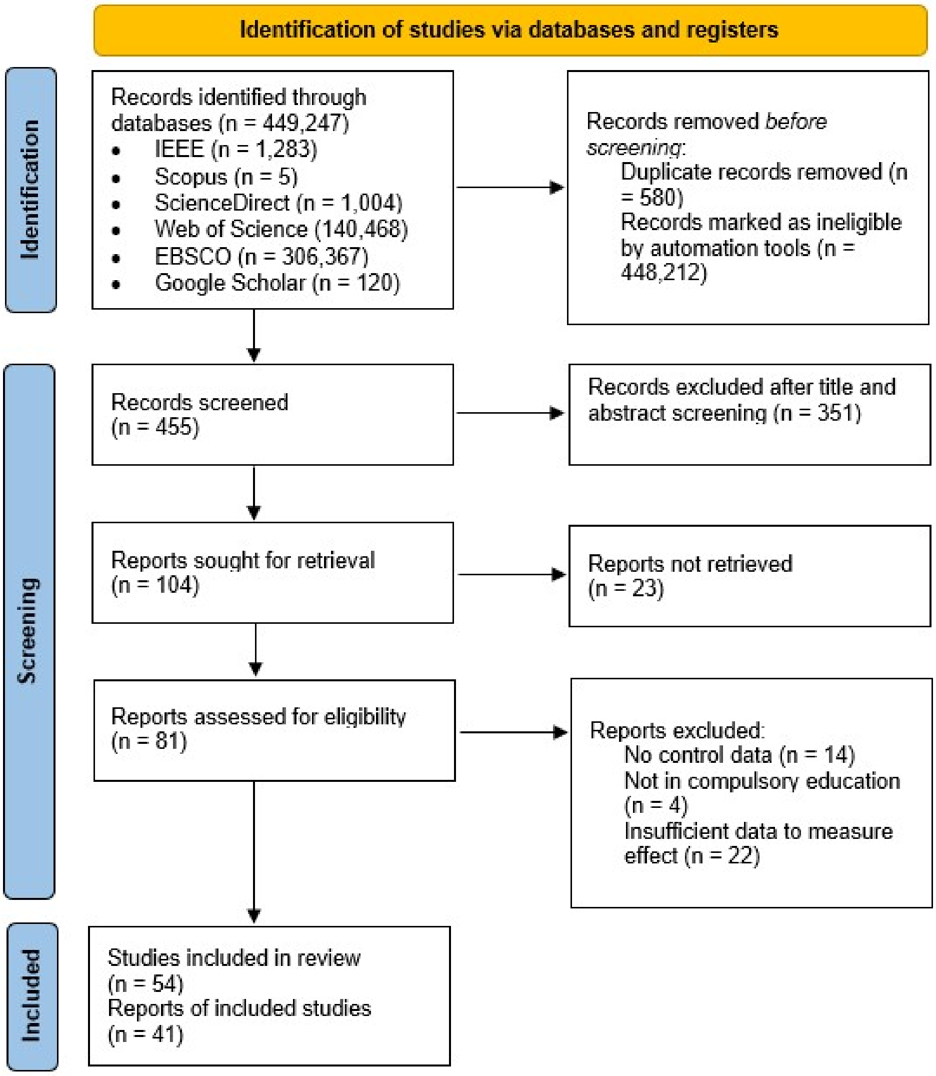

Figure 1: PRISMA Flow Diagram of Study Selection

3.3 Inclusion and Exclusion Criteria

Studies were eligible for inclusion if they met the following criteria:

- Empirical studies published between 2010 and 2025 that investigated the use of gamification in mathematics education.

- Studies reporting quantitative outcomes related to engagement, motivation, or academic performance.
- Availability of statistical information sufficient to compute or extract effect sizes (e.g., means, standard deviations, or sample sizes).

Studies were excluded if they:

- Focused solely on game-based learning (GBL) without explicit gamification elements;
- Were theoretical, qualitative, or non-empirical;
- Lacked control or comparison groups;
- Were non-English publications or lacked full-text access.

3.4 Data Extraction and Coding

From each eligible study, the following data were extracted: author(s), year of publication, country, educational level, sample size, gamification elements used (e.g., leaderboards, points, badges, narratives) and measured results (achievement scores, engagement ratings, or motivation indices). Each study was coded according to these characteristics to enable subgroup and moderator analyses.

3.5 Research Hypothesis

Based on prior empirical evidence and the theoretical frameworks discussed, this study formulated and tested the following hypotheses:

- **Null Hypothesis (H_0)**: Gamification has no significant effect on students' engagement and achievement in mathematics education; that is, the true effect size equals zero.
- **Alternative Hypothesis (H_1)**: Gamification significantly enhances students' engagement and achievement in mathematics education; that is, the true effect size is greater than zero.

These hypotheses were tested statistically through meta-analytic procedures using both fixed-effect and random-effects models. A significance level of $p < 0.05$ was adopted to determine whether the null hypothesis should be rejected.

3.6 Effect Size Calculation

Effect sizes were computed using the standardised mean difference (SMD), represented by Cohen's d and Hedges' g, to ensure comparability across diverse outcome measures (15; 16). Cohen's d was calculated as:

$$d = \frac{\mu_1 - \mu_2}{SD_{\text{pooled}}}$$

where μ_1 and μ_2 represent the mean scores of the experimental (gamified) and control (non-gamified) groups, respectively. Hedges' g was derived to correct for small-sample bias using:

$$g = J \times d, \quad J = 1 - \frac{3}{4N - 9}$$

where $N = n_1 + n_2$ is the combined sample size of both groups. Confidence intervals (95%) were calculated, and standard errors (SE) were estimated as:

$$SE = \frac{CI_{\text{upper}} - CI_{\text{lower}}}{2 \times 1.96}$$

These values were subsequently used to estimate study weights in the meta-analysis.

3.7 Assessment of Heterogeneity

Heterogeneity across studies was assessed using Cochran's Q statistic and the I^2 index (17). Q was calculated as:

$$Q = \sum w_i (g_i - \bar{g})^2$$

where w_i denotes study weight and g_i the observed effect size. The I^2 statistic represents the proportion of variance attributable to true heterogeneity rather than sampling error and was interpreted as low (25%), moderate (50%), or high (75%) heterogeneity.

3.8 Publication Bias and Sensitivity Analysis

Potential publication bias was evaluated through visual inspection of funnel plot and the Egger's regression test, defined as (18; 19):

$$SND_i = \alpha + \beta \times \text{Precision}_i + \varepsilon_i$$

where SND_i denotes the standard normal deviate and Precision_i is the inverse of the standard error. A non-significant intercept ($p > 0.05$) indicates absence of substantial bias. Sensitivity analyses were conducted by comparing pooled results under fixed-effect and random-effects models to ensure robustness.

3.9 Summary of Analytical Procedure

All the analysis were performed following the PRISMA 2020 protocol for systematic reviews and meta-analysis. The statistical workflow involved the identification and selection of studies, the extraction of effect size, the heterogeneity testing, the evaluation of bias and the synthesis of the pooled results. The meta-analysis produced a consolidated estimate of the effect of gamification on mathematics achievement and engagement.

4 Results and Discussion

4.1 Overview of Findings

The meta-analysis synthesised quantitative data from 41 studies (comprising 54 independent samples) that examined the impact of gamification on mathematics education across primary, secondary, and higher education levels as shown in Table 1. Summary fo the studies can be found in the appendix. Collectively, these studies involved more than 6,000 participants and implemented a variety of gamification elements including leaderboards, points, badges, and narrative missions.

The demographics of the included studies are illustrated in the charts below. The pie chart (Figure 2) shows the percentage of studies conducted in each country.

Further analysis of the pie chart by continent indicates that Asia accounts for the largest proportion of studies (48%), whereas Oceania contributes the smallest proportion (2%). This distribution is likely related to the relative size of research output and investment in education across regions.

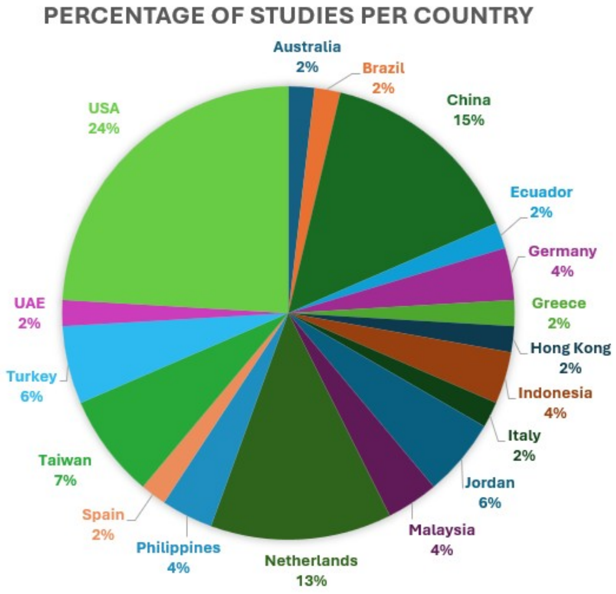

Figure 2: Distribution of studies by country

Table 1: Summary of Included Studies by Educational Level

Education Level	**Number of Studies**
Primary	27
Secondary	19
University	8
Total	**54**

Table 2: Overall Effect Sizes and Heterogeneity Statistics

Model	**Effect Size (Hedges' g)**	**95% CI**	Q	I^2
Fixed-effect	0.48	[0.42, 0.53]	583.87	90.9%
Random-effects	0.66	[0.46, 0.85]	583.87	90.9%

The random-effects model yielded a pooled effect size of $g = 0.66$ with 95% confidence intervals [0.46, 0.85], $p < 0.001$, indicating a moderate positive effect of gamification on students' engagement and learning outcomes as depicted in Table 2. The fixed-effect model produced a comparable but slightly lower estimate ($g = 0.48$, 95% CI [0.42, 0.53]). Both confirm that gamification has a statistically significant positive impact on mathematics learning.

The magnitude of these effect sizes suggests that gamification exerts a meaningful and educationally relevant influence on learners' performance and engagement in mathematics. Although the effect is moderate, it represents a consistent improvement across diverse instructional settings and participant groups. This finding reinforces the theoretical claim that incorporating game elements, such as points, badges, and progress feedback, can stimulate intrinsic motivation and sustained participation. Consequently, the integration of gamification into mathematics curricula appears to enhance both cognitive and affective dimensions of learning.

4.2 Heterogeneity and Subgroup Analysis

A high degree of heterogeneity was observed across studies ($I^2 = 90.9\%$), suggesting considerable variation in effect sizes due to differences in educational level, intervention type and contextual implementation as seen in Table 2. Cochran's $Q = 583.87$ (df = 53, $p < 0.001$) further confirmed that variability could not be explained by sampling error alone.

Subgroup analysis revealed that the largest effects were observed in secondary education ($g = 0.77$), followed by primary ($g = 0.59$) and higher education ($g = 0.54$), shown in Table 3. Although all levels demonstrated significant gains, heterogeneity was highest in primary and secondary studies, indicating that contextual and design factors strongly influence efficacy.

These findings indicate that the variability across studies is not merely random but is likely influenced by meaningful differences in study design, participant demographics, and the specific nature of the gamification strategies implemented. The high I^2 value suggests that the effectiveness of gamification in mathematics education depends substantially on contextual and pedagogical factors rather than a single uniform effect. For instance, the stronger outcomes observed in secondary education may reflect the increased cognitive maturity of learners at this level, enabling them to respond more positively to competitive and goal-oriented tasks. Conversely, the lower yet significant effects in primary and higher education suggest that gamification remains beneficial, although its success may rely more heavily on age-appropriate design and its integration with curricular content.

Table 3: Subgroup Analysis of Effect Sizes by Educational Level

Educational Level	**Number of Studies**	**Effect Size (Hedges' g)**	**95% CI**
Primary	27	0.59	[0.33, 0.85]
Secondary	19	0.77	[0.51, 1.02]
Higher	8	0.54	[0.26, 0.82]

The forest plot presented in Figure 3 visually summarises the effect sizes of all included studies alongside their 95% confidence intervals. Each horizontal line represents an individual study, with the square marker indicating the estimated effect size and its size proportional to the study's weight in the meta-analysis. The vertical line at zero represents the line of no effect, and studies positioned to the right of this line indicate a positive effect of gamification on mathematics learning outcomes. The diamond at the bottom of the plot represents the overall pooled effect size, which in this analysis demonstrates a moderate and statistically significant benefit in favour of gamified instruction. The wide spread of confidence intervals across studies further illustrates the high level of heterogeneity ($I^2 = 90.9\%$) observed in the dataset.

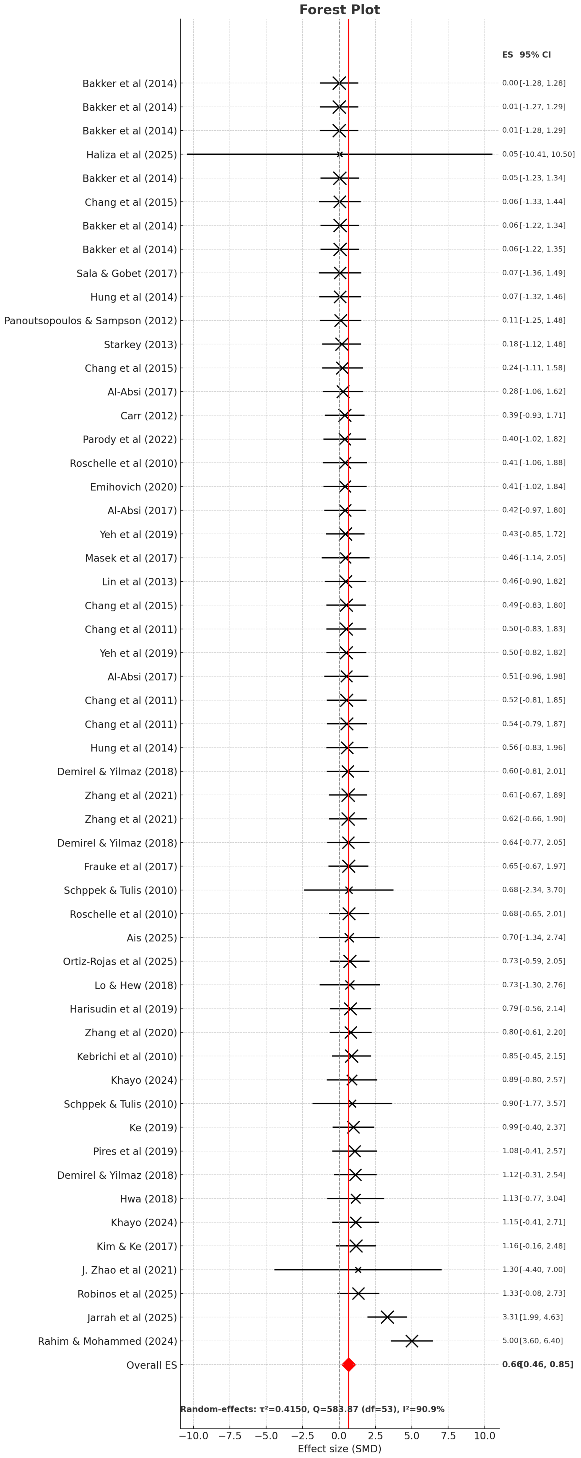

Figure 3: Forest plot showing individual study effect sizes (Hedges' g) and the overall pooled estimate for gamification interventions in mathematics education.

4.3 Publication Bias and Sensitivity Tests

The funnel plot (Figure 4) displayed mild asymmetry and Egger's regression test returned an intercept of 1.74 ($p = 0.052$), suggesting weak evidence of publication bias. Given the high heterogeneity ($I^2 > 90\%$), the asymmetry is likely to be attributable to variation between study designs rather than systematic bias. Sensitivity analysis comparing fixed and random-effects models yielded consistent findings, reinforcing the robustness of the results.

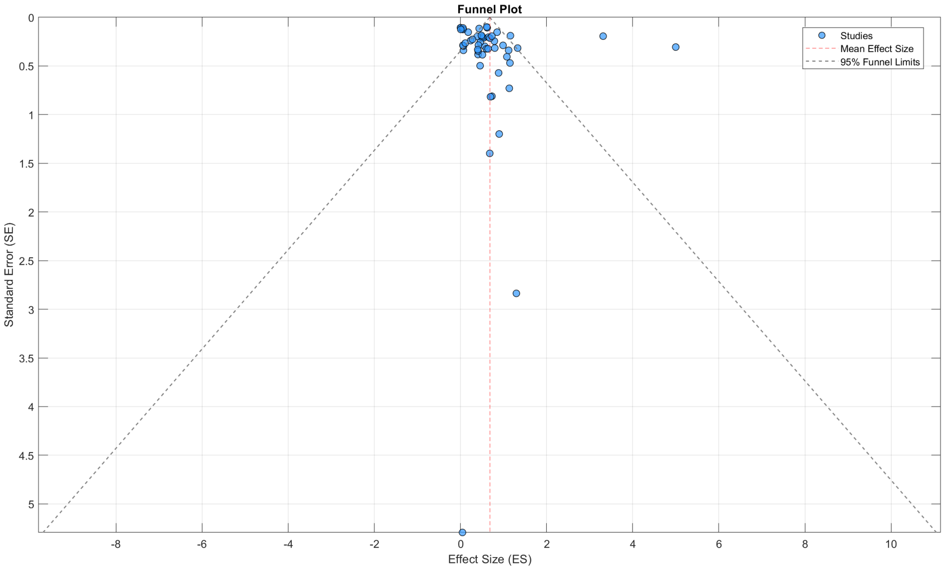

Figure 4: Funnel plot illustrating study distribution for publication bias analysis.

4.4 Interpretation of Findings

The results provide strong evidence that gamification exerts a moderate, statistically significant positive effect on student engagement and mathematics achievement. The rejection of the null hypothesis (H_0) supports the conclusion that gamification has a statistically significant positive influence on mathematics learning outcomes. This finding aligns with previous meta-analytic evidence in educational psychology, confirming that well-designed gamified environments enhance motivation and learning performance compared with traditional instructional approaches.

From the perspective of Self-Determination Theory (SDT), gamified learning satisfies the core psychological needs of autonomy, competence, and relatedness, fostering intrinsic motivation. The positive pooled effect size supports the proposition that these motivational gains translate into improved cognitive and behavioural engagement.

In relation to Cognitive Load Theory (CLT), gamification appears to reduce extraneous cognitive load by structuring tasks into progressive challenges and providing immediate feedback. This scaffolding supports germane cognitive load, allowing learners to devote mental resources to problem-solving and schema construction in mathematics.

Constructivist Pedagogy also explains the observed benefits such as, gamified learning environments encourage experimentation, active exploration, and iterative problem-solving. The use of challenges and immediate feedback fosters deeper conceptual understanding and promotes sustained engagement, key components of mathematical fluency.

4.5 Moderating Factors and Variability

The significant heterogeneity indicates that gamification's effectiveness depends on several moderating variables:

- **Design Quality:** Interventions that combine multiple game elements (points, badges, leaderboards and narrative) yield stronger effects than those using a single element, such as points alone.
- **Educational Context:** Secondary education demonstrated the highest mean effect size, possibly because students in this stage respond well to competitive and goal-oriented tasks.
- **Teacher Competence:** Effective implementation depends on teachers' ability to integrate gamification meaningfully into pedagogy. Poorly designed interventions risk superficial engagement or over-reliance on extrinsic rewards.

4.6 Comparison with Previous Research

The results corroborate prior reviews that reported improvements in learner motivation, engagement and test performance (1; 7). However, the observed variability across studies supports the claim that "one-size-fits-all" gamification strategies are ineffective. Contextual adaptation, particularly to subject difficulty and student demographics, remains essential for maximising outcomes.

4.7 Practical Implications

The findings of this meta-analysis have several important implications for educators, curriculum designers, and educational policymakers. First, effective gamified instruction should prioritise the development of intrinsic motivation by aligning game mechanics with clearly defined learning objectives. Rather than relying solely on external rewards such as points or badges, educators should design activities that cultivate autonomy, competence and relatedness, core principles of Self-Determination Theory. When learners perceive gamified tasks as meaningful and self-directed, they are more likely to engage deeply and sustain their interest in mathematics.

Furthermore, the successful implementation of gamification requires continuous professional development (CPD) for teachers. Training programmes should focus not only on the technical use of gamification tools but also on the pedagogical understanding of how game elements can enhance learning outcomes. Teachers who are well-equipped with these skills are better able to integrate gamified approaches creatively and adapt them to the diverse needs and abilities of their students.

Finally, a balanced approach that combines enjoyment with appropriate cognitive challenge is essential. When game elements are designed to be both engaging and intellectually stimulating, they can reduce mathematics anxiety and foster persistence in problem-solving. Gamification should therefore be viewed not as a superficial layer of entertainment but as a deliberate instructional design strategy that promotes motivation, concentration, and sustained achievement in mathematics learning.

5 Conclusions

This study conducted a quantitative synthesis of 41 empirical investigations (54 independent samples) examining the efficacy of gamification in mathematics education. The meta-analysis revealed a moderate and statistically significant positive effect ($g = 0.66$, 95% CI [0.46, 0.85]) on student engagement, motivation, and academic performance. These findings confirm that gamification, when thoughtfully designed and implemented, can transform traditional mathematics instruction into a more interactive and intrinsically motivating experience. By integrating psychological, cognitive and pedagogical theories, specifically Self-Determination Theory, Cognitive Load Theory and Constructivist Pedagogy, gamification fosters autonomy, competence and relatedness, all of which contribute to sustained engagement and improved learning outcomes.

Despite the strength of these results, several limitations must be acknowledged. First, high heterogeneity ($I^2 = 90.9\%$) suggests considerable variability in design, context and participant characteristics across studies, which constrains generalisability. Second, while the Egger's regression test indicated only weak evidence of publication bias ($p = 0.052$), the exclusion of some unpublished or non-English studies may have marginally influenced the overall effect size. Third, many of the included interventions were short-term, offering limited insight into the long-term sustainability of gamification's effects on learning and motivation. Finally, most studies focused primarily on students, while the role of teacher competence, pedagogical training, and cultural context remains underexplored.

Future research should therefore prioritise longitudinal designs to assess the durability of gamification's motivational and cognitive benefits over time. Further studies are also needed to examine how teacher expertise and pedagogical design mediate outcomes, particularly in higher education settings where gamification remains underutilised. In addition, cross-cultural comparisons could provide valuable insights into how contextual and cultural factors influence student responses to gamified learning environments. A more standardised taxonomy of game elements and clearer reporting of implementation strategies would also enhance replicability and comparability in future meta-analyses.

In conclusion, this meta-analysis demonstrates that gamification represents a powerful pedagogical approach for enhancing mathematics learning when underpinned by sound theoretical principles and supported by competent implementation. It offers a pathway towards reducing mathematics anxiety, improving persistence and fostering deep engagement with mathematical concepts. While challenges remain, particularly in ensuring pedagogical rigour and long-term sustainability, the evidence presented here affirms gamification's potential as an innovative and effective strategy for mathematics education in diverse learning contexts.

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Appendix-- Summary of Included Studies

Table 4: Summary of studies on gamification in mathematics education.

Author	**Year**	**Country**	**Level**	**Game / Element(s)**	**n**	**Outcome Measured**
Ais (20)	2025	Philippines	Secondary	Leaderboard, badges & points	54	Academic performance
Al-Absi (21)	2017	Jordan	Undergraduate	Puzzles & games	38	Student engagement
Al-Absi	2017	Jordan	Undergraduate	Puzzles & games	14	Motivation
Al-Absi	2017	Jordan	Undergraduate	Puzzles & games	24	Motivation
Bakker et al. (22)	2014	Netherlands	Primary	Online mini games	439	Student engagement

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Author	**Year**	**Country**	**Level**	**Game / Element(s)**	**n**	**Outcome Measured**
Bakker et al.	2014	Netherlands	Primary	Online mini games	405	Student engagement
Carr (23)	2012	USA	Primary	iPad maths games	104	Academic performance
Chang et al. (24)	2011	Taiwan	Primary	Game scenarios	92	Student engagement
Chang et al. (25)	2015	USA	Secondary	The Math App	72	Academic performance
Chang et al.	2015	USA	Secondary	The Math App	120	Academic performance
Chang et al.	2015	USA	Secondary	The Math App	74	Academic performance
Demirel & Yilmaz (26)	2018	Turkey	Secondary	Mind game	40	Academic performance
Emihovich (27)	2020	USA	Undergraduate	Video gameplay	34	Student engagement
van der Ven et al. (28)	2017	Netherlands	Primary	Tablet racing game	103	Student engagement
Haliza et al. (29)	2025	Indonesia	Primary	Prodigy	60	Academic performance
Harisudin et al. (30)	2019	Indonesia	Secondary	Bridge games	72	Student engagement
Hung et al.(31)	2014	China	Primary	Brick Breaker game	46	Academic performance
Hwa (32)	2018	Malaysia	Primary	DigiGEMs	20	Student engagement
Zhao et al.(33)	2021	China	Primary	Gamified IEB	90	Academic performance
Jarrah et al. (34)	2025	UAE	Secondary	Kahoot	60	Academic performance
Ke (35)	2019	USA	Secondary	Simulation game	61	Academic performance
Kebritchi et al. (36)	2010	USA	Secondary	Computer game	193	Academic performance
Khayo (37)	2024	USA	Undergraduate	Kahoot	35	Academic performance
Khayo	2024	USA	Undergraduate	Kahoot	36	Academic performance
Kim & Ke (38)	2017	USA	Primary	OpenSim VR	132	Academic performance
Lin et al. (39)	2013	Taiwan	Primary	Monopoly game	62	Academic performance
Lo & Hew (40)	2018	Hong Kong	Secondary	Leaderboard etc.	55	Academic performance
Masek et al. (41)	2017	Australia	Primary	Video gameplay	131	Academic performance
Ortiz-Rojas et al. (42)	2025	Ecuador	Undergraduate	Leaderboard	175	Academic performance
Panoutsopoulos & Sampson (43)	2012	Greece	Secondary	Sims 2: Open for Business	57	Academic performance
Parody et al. (44)	2022	Spain	Undergraduate	Classcraft	38	Motivation
Pires et al. (45)	2019	Brazil	Primary	Gamified didactic sequence	28	Academic performance
Rahim & Mohammed (46)	2024	Malaysia	Primary	Kahoot	54	Academic performance
Robinos et al. (47)	2025	Philippines	Secondary	Kahoot	29	Academic performance
Roschelle et al.(48)	2010	USA	Secondary	SimCalc	1621	Student engagement
Roschelle et al.	2010	USA	Secondary	SimCalc	825	Student engagement
Sala & Gobet (49)	2017	Italy	Primary	Chess	35	Student engagement
Schröpp & Tulis (50)	2010	Germany	Primary	Merlin’s Math Mill	110	Academic performance
Schröpp & Tulis	2010	Germany	Primary	Merlin’s Math Mill	94	Academic performance
Starkey (51)	2013	USA	Secondary	Labyrinth	168	Academic performance
Yeh et al. (52)	2019	China	Primary	Math-Island	114	Academic performance
Yeh et al.	2019	China	Primary	Math-Island	334	Academic performance
Zhang et al. (53)	2020	China	Primary	Tablet learning game	65	Academic performance
Zhang et al. (54)	2021	China	Secondary	Classcraft	36	Academic performance
Zhang et al.	2021	China	Secondary	Classcraft	34	Motivation