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Can digital games ease cognitive load? A systematic review and meta-analysis in mathematics learning

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Abstract: Mathematics learning often burdens students' cognitive capacity, hindering their understanding of concepts and mastery of the material. Digital Game-Based Learning (DGBL) offers a promising approach to address this challenge, but its effectiveness remains a subject of debate. This research employs a Systematic Literature Review and meta-analysis to analyze 15 empirical studies. The primary objective is to evaluate the impact of DGBL on cognitive load, identify research trends, and determine the factors that moderate its effectiveness. The meta-analysis definitively demonstrates that DGBL has a significant and medium effect on reducing students' cognitive load in mathematics learning. Further analysis reveals that the type of mathematics content and game genre act as significant moderators. Specifically, DGBL exhibits superior effectiveness in reducing cognitive load with algebra and geometry material compared to arithmetic, percentages, patterns, number lines, and graphs. Moreover, simulation and puzzle genres prove more effective than role-playing and adventure genres. This research highlights the importance of carefully considering the selection of content and game genre when implementing DGBL to optimize the reduction of cognitive load in elementary schools. These findings provide valuable insights for educators and educational software developers in designing more effective learning interventions tailored to students' needs.

Keyword: Digital games; mathematics learning; cognitive load; meta-analysis

Dapatkah game digital menurunkan beban kognitif? Tinjauan sistematis dan meta-analisis pada pembelajaran matematika

Abstrak: Pembelajaran matematika seringkali membebani kapasitas kognitif siswa, menghambat pemahaman konsep dan penguasaan materi. *Digital Game-Based Learning (DGBL)* menawarkan pendekatan yang menjanjikan untuk mengatasi tantangan ini, tetapi efektivitasnya masih menjadi perdebatan. Penelitian ini menggunakan Systematic Literature Review dan meta-analisis untuk menganalisis 15 studi empiris. Tujuan utama adalah untuk mengevaluasi dampak DGBL pada beban kognitif, mengidentifikasi tren penelitian, dan menentukan faktor-faktor yang memoderasi efektivitasnya. Meta-analisis secara definitif menunjukkan bahwa DGBL memiliki pengaruh yang signifikan dan sedang dalam mengurangi beban kognitif siswa dalam pembelajaran matematika. Analisis lebih lanjut mengungkapkan bahwa jenis konten matematika dan genre game bertindak sebagai moderator yang signifikan. Secara khusus, DGBL menunjukkan efektivitas yang lebih unggul dalam mengurangi beban kognitif pada materi aljabar dan geometri dibandingkan dengan aritmatika, persentase, pola, garis bilangan, dan grafik. Selain itu, genre simulasi dan teka-teki terbukti lebih efektif daripada genre role-playing dan petualangan. Penelitian ini menyoroti pentingnya mempertimbangkan dengan cermat pemilihan konten dan genre game saat menerapkan DGBL untuk mengoptimalkan pengurangan beban kognitif di sekolah dasar. Temuan ini memberikan wawasan berharga bagi para pendidik dan pengembang perangkat lunak pendidikan dalam merancang intervensi pembelajaran yang lebih efektif yang disesuaikan dengan kebutuhan siswa.

Kata Kunci: Game digital; pembelajaran matematika; beban kognitif; meta analisis

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INTRODUCTION

Learning mathematics is often perceived as a challenging subject that imposes a high cognitive load on students (Avgerinou & Tolmie, 2020). The abstract and complex nature of mathematical concepts, which demand logical thinking skills, frequently burdens students' working memory capacity, thereby hindering their comprehension and mastery of the material (Al-Barakat et al., 2025). This can negatively affect students' motivation, achievement, and mathematical skills (Metwally et al., 2024). Students often need to dedicate significant additional time to grasp mathematical material, particularly when conventional methods are employed (Prabowo et al., 2020). This exhausting academic burden leads to a lack of enthusiasm and motivation toward mathematics (Moussa-Inaty et al., 2020), creating dilemmas such as unsatisfactory knowledge mastery coupled with low motivation and high cognitive load (Mooij et al., 2020). Therefore, innovative approaches to mathematics education are needed to reduce cognitive load and enhance learning effectiveness.

Digital game-based learning (DGBL), recognized as a leading 21st-century pedagogical approach, offers significant advantages in enhancing learning outcomes and motivation, while simultaneously reducing cognitive load during the learning process (Cai et al., 2022). Digital games create engaging learning environments where learners can interact with game mechanics within a virtual world. This interaction provides meaningful and enjoyable experiences, fostering increased learning motivation (Ilić et al., 2024). Integrating game elements, such as digital games, into learning activities has proven to be enjoyable, preventing students from feeling overwhelmed by the material (Yang & Chen, 2023). Research indicates that digital games effectively reduce cognitive load in educational settings, from elementary schools (Arztmann et al., 2025) to higher education (Stiller & Schworm, 2019). Consequently, leveraging the potential of digital games to promote meaningful and enjoyable learning can be a valuable strategy for minimizing unnecessary cognitive load during instruction.

Research on the effectiveness of Digital Game-Based Learning (DGBL) in reducing cognitive load in elementary school mathematics learning has yielded mixed results. While DGBL has the potential to increase motivation and learning outcomes, its effectiveness in reducing cognitive load remains debated. Some studies indicate that DGBL can help students reduce intrinsic and extrinsic cognitive load in mathematics learning (Chen & Huang, 2023; Kahyaoğlu Erdoğmuş & Kurt, 2023; Lin et al., 2021), while others argue that DGBL may not offer a significant advantage over traditional methods (Barz et al., 2024; Chang & Yang, 2023; Faber et al., 2024; Hawlitschek & Joeckel, 2017; Zhang & Yu, 2025). Moreover, existing reviews and meta-analyses on gamified learning have not specifically examined the scope of mathematics learning in elementary schools when analyzing the reduction of cognitive load. These existing studies have primarily focused on the success of DGBL in improving learning outcomes (Gui et al., 2023; Tlili et al., 2024). Therefore, a more comprehensive study is needed to summarize existing research results and identify factors that moderate the effectiveness of DGBL in reducing cognitive load in elementary school mathematics learning. Research on using digital games to teach math is urgent because games can make learning more engaging and improve results, especially for younger students. Studies show games help students learn and think better. However, we need to figure out how to design games that aren't overwhelming and that fit well with what's being taught in class. A systematic literature review and meta-analysis are necessary to synthesize disparate findings and provide a clearer picture. This approach allows for the identification of patterns and factors that moderate the effectiveness of DGBL, which cannot be achieved by reviewing studies individually.

Employing a Systematic Literature Review and meta-analysis, this study aims to provide stronger empirical evidence regarding the extent to which DGBL can reduce students' cognitive load, and to determine what material content and game genres most influence the success of DGBL in this reduction. The findings of this research are expected to provide valuable insights for developing effective and efficient mathematics learning strategies that leverage the potential of digital game technology. Specifically, this research aims to answer the following questions:

RQ1. What are the trends and characteristics of Digital Game-Based Learning (DGBL) in mathematics education?

RQ2. What is the effect of DGBL on cognitive load in mathematics education?

RQ3. What DGBL optimization strategies can be applied when selecting content and game genres to reduce cognitive load in mathematics education?

METHOD

Research Design

This research employs a Systematic Literature Review (SLR) methodology (Zou et al., 2022) and meta-analysis (Cooper et al., 2009) to comprehensively analyze and summarize existing literature regarding the effectiveness of digital game-based learning in reducing cognitive load within the context of elementary school mathematics education. This study also specifically investigates the factors influencing the effectiveness of digital game-based learning on the reduction of cognitive load. Systematic reviews and meta-analyses are widely recognized research methods that enable the synthesis of existing studies and provide a robust and comprehensive overview of a specific research topic. Meta-analysis, on the other hand, involves the statistical aggregation of effect sizes from individual studies, allowing for a quantitative estimation of the overall impact of digital game-based learning (DGBL) on the cognitive load of mathematics learning in elementary schools.

Literature retrieval and screening

The literature search in this article strictly followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria to identify relevant empirical research studies (Moher et al., 2009). The article search was conducted on the Scopus database using three sets of keywords: (“digital game-based learning” OR “digital game” OR “educational game” OR “simulation game” OR “electronic game” OR “computer game” OR “video game”), AND cognitive load (“cognitive load” OR “intrinsic load” OR “extraneous load” OR “mental load” OR “mental effort”), AND mathematics learning (“mathematics learning”

OR “mathematics education” OR “math learning” OR “mathematic”) to screen the literature in the Scopus database. A total of 152 articles were identified and imported into Mendeley for further examination. After duplicate articles were removed, the titles and abstracts of the remaining 135 entries were examined by the research team for relevance and suitability to the topic of this article. Following an initial screening based on the title and abstract of each article, checking if the study was an experimental or quasi-experimental study on the effects of DGBL in reducing cognitive load, the list was narrowed down to 89 studies for further full-text reading. To screen these studies, we developed and applied inclusion/exclusion criteria. A study was excluded if it (1) was conducted before 2019 or after 2025, (2) was not written in English, (3) was not an empirical study, (4) did not use digital devices when playing educational games, (5) was a qualitative study or a review, or (6) did not provide sufficient information to calculate the effect size. Finally, 15 studies were identified as meeting the inclusion criteria and were thus included in the SLR and meta-analysis process. The selected articles were from the years 2018 to 2025, considering that this period captures the phenomenon of accelerated digital game usage, as evidenced by the increase in its implementation in the field of education (Ilić et al., 2024). The flow chart of the study screening is shown in Figure 1.

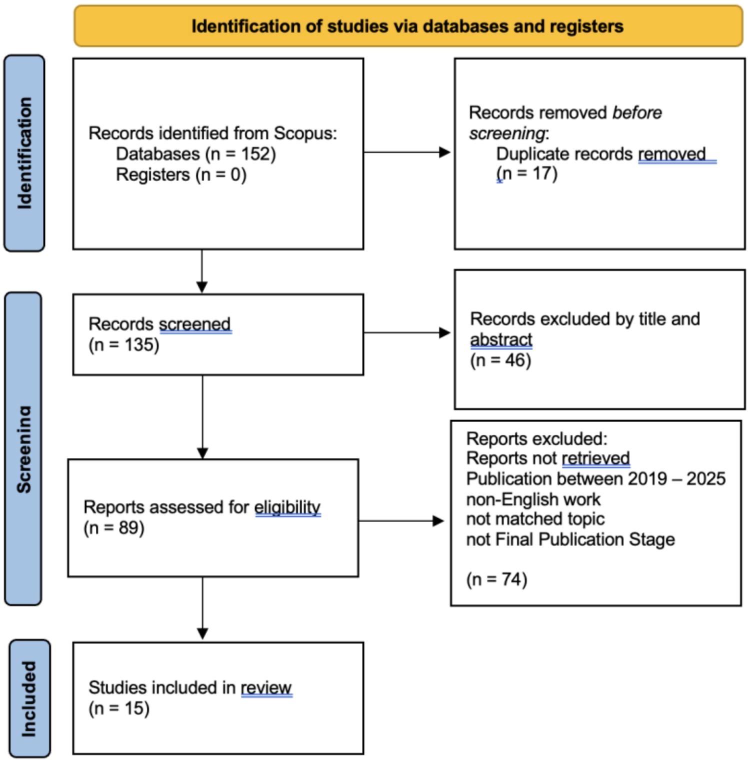

Figure 1. PRISMA Diagram

As a result, 15 studies (totaling 1,130 participants) were included in this meta-analysis: 1 study was published in 2019 (Liao et al., 2019); 2 in 2021 (Chu et al., 2021; Weijer-Bergsma & Ven, 2021); 3 in 2022 (Cho et al., 2022; Zhong, 2022); 3 in 2023 (Chen & Huang, 2023; Huang et al., 2023; Shi et al., 2023); 2 in 2024 (Karabay & Meşe, 2024; Wang et al., 2024); and 4 in 2025 (Fang et al., 2025; Jhang et al., 2025; Miller-Cotto & Medrano, 2025; Xiang et al., 2025). Figure 1 presents a flow chart illustrating the study selection process.

Coding of studies

Several prominent characteristics (e.g., content type and game genre) were considered as potential moderators that could influence the findings across the primary studies. These moderator variables were coded into different levels. To classify the genres of digital games, this research refers to the framework by Gui et al. (2023), which classifies games based on eight genres: (1) simulation, mimicking real-world scenarios and providing activities that players must successfully complete; (2) adventure games, placing players in an interactive story where they must explore the game environment to complete game missions; (3) quiz games, focusing on answering various challenging questions; (4) role-playing games, allowing players to take on specific roles within the game through game characters to achieve game objectives; and (5) puzzle games, often requiring players to solve puzzles through logical thinking.

Statistical analyses

Calculations for the meta-analysis were performed using RStudio to analyze the data extracted from the primary studies. In addition, Hedges' g was used to calculate the effect size (Cooper et al., 2009). The rationale for using Hedges' g rather than Cohen's d as the effect size is that differences in sample size among studies can affect the effect size estimates. This bias affects studies with sample sizes less than 20, where Hedges' g provides a more reliable estimate than Cohen's d (Brydges, 2019). According to Thalheimer & Cook (2002) guidelines for interpreting effect sizes, an effect size is considered non-significant if $-0.15 < g < 0.15$; small if $0.15 \le g < 0.40$; medium if $0.40 \le g < 0.75$; large if $0.75 \le g < 1.10$; very large if $1.10 \le g < 1.45$; and extremely large if $g \ge 1.45$. Furthermore, to test whether there was heterogeneity in the variation of effect sizes within the reviewed studies, Q and I^2 were evaluated. A random-effects model was used in the meta-analysis when significant heterogeneity was present ($I^2 > 50\%$), while a fixed-effects model was applied when heterogeneity was not significant ($I^2 \le 50\%$) (Higgins & Thompson, 2002).

Publication bias

Publication bias was evaluated using funnel plots, Egger's regression intercept, and the trim-and-fill method (Egger et al., 1997). Egger's regression intercept uses a significant t-test to indicate asymmetry. If asymmetry is detected, the trim-and-fill method estimates how many studies should be removed, added, or trimmed from one side of the funnel plot for the remaining effect size to be symmetrical. Publication bias will be considered "absent or negligible" if the p-value of Egger's test is > 0.05 at a 95% significance level. The results of the publication bias analysis indicate:

Table 1. Publication Bias

Test Name	value	p
Fail-Safe N	492.000	<.001
Begg and Mazumdar Rank Correlation	-0.371	0.059
Egger's Regression	-1.938	0.053
Trim and Fill Number of Studies	0.000	.

Analysis of the funnel plot (Figure 2) and Egger's test indicated no evidence of publication bias, as demonstrated by an Egger's test p-value of 0.053, which is greater than 0.05 (Table 1). Therefore, the concern regarding publication bias was not substantiated. This suggests that the results of this study are stable and valid, and are representative of all existing studies. The Fail-safe N calculation revealed that 492 studies with non-significant results would be required to nullify the effect of the meta-analysis. This indicates that the findings of this study are relatively stable and reliable, suggesting that the conclusions drawn are robust and not easily refuted.

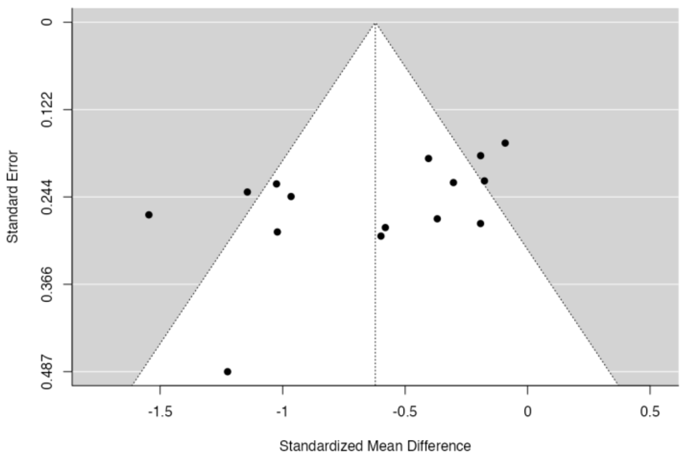

Figure 2. Funnel Plot

RESULT AND DISCUSSION

Trends and Characteristics of Digital Game-Based Learning (DGBL) in Mathematics Education

Research Trends Related to DGBL and Cognitive Load in Mathematics Education

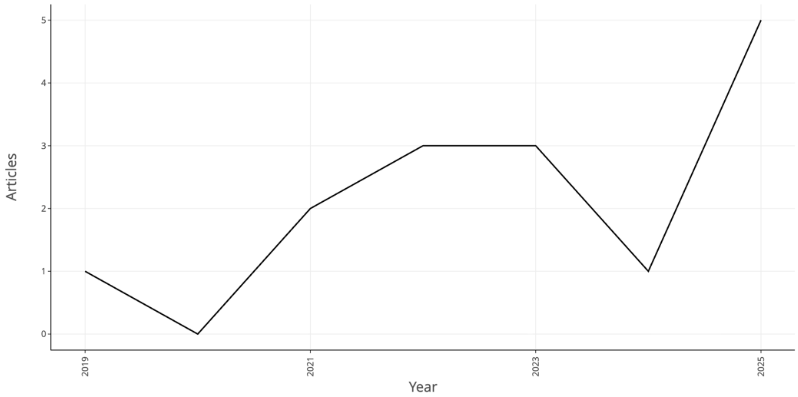

Figure 3. Research Trends Over the Years

Research related to Digital Game-Based Learning and Cognitive Load in mathematics education has been published over the past few years. Figure 3 illustrates fluctuating trends between 2019 and 2025. In 2019, one article was published. This increased to two articles in 2021, and then to three articles in 2023. A significant increase occurred between 2023 and 2025, with five articles being published. This indicates that research topics related to digital games and cognitive load, particularly within the context of mathematics, remain popular, with a notable surge in publications in 2025.

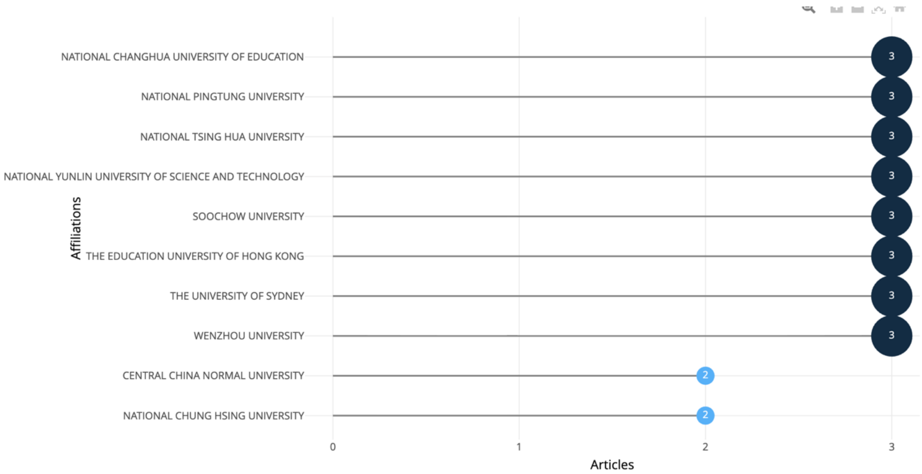

Figure 4. Affiliate Contributions

Several affiliations contribute roughly equally to this topic (Figure 4), with each affiliation contributing an average of three articles related to DGBL and cognitive load in mathematics learning. The affiliations with the highest contribution are primarily universities located in Taiwan, indicating a strong research center in that country.

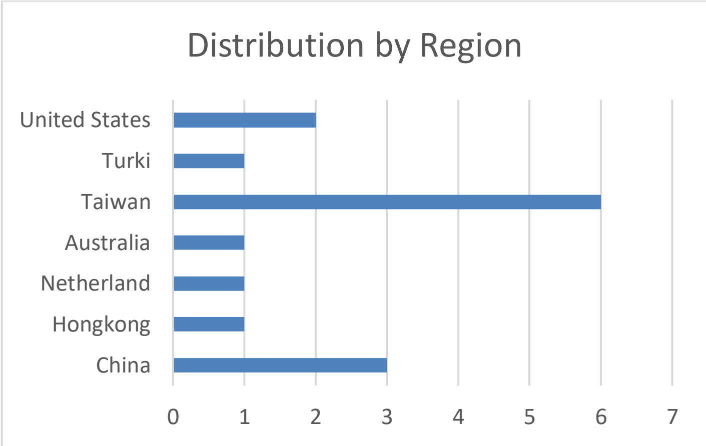

Figure 5. Research Distribution by Country

As shown in Figure 5, the three countries that contributed the most to this field are Taiwan (n=6), China (n=3), and the United States (n=4). Figure 5 illustrates the geographical distribution of these 15 studies. The mathematical content or material discussed in the various studies related to DGBL and cognitive load is highly diverse, as can be seen in the following table:

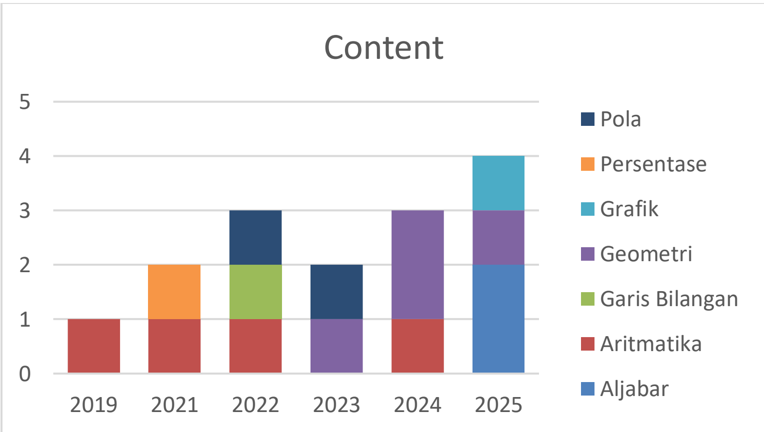

Figure 6. Distribution of Content Types by Year

Arithmetic content has evolved since the beginning (2019), as shown in Figure 6. Content on percentages appeared only once in 2021. Similarly, content related to number lines also appeared only once, with one article in 2022. Geometry content first appeared in 2023 and then dominated in 2024. In contrast, in 2025, algebra content was researched more extensively, accompanied by content on graphs, which newly appeared that year. Overall, geometry content has been in considerable demand for research over the last three years.

Game Genre Trends Adopted in Mathematics Learning to Reduce Cognitive Load

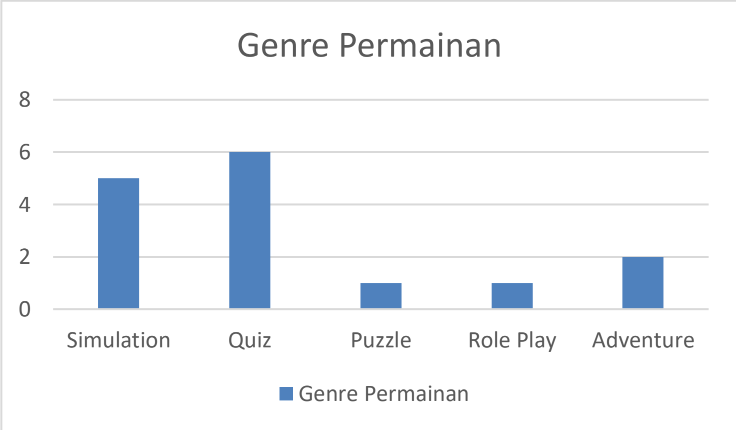

Figure 7. Trends in Game Genre Adopted

As shown in Figure 7, game genres predominantly used in research involve mini-quiz games. In these games, players are prompted to learn and practice by answering questions (riddles) within a specific time limit, subsequently earning a certain score. The next most dominant genre is simulation games. These games typically present an environment or conditions that mimic real-world situations, allowing players to learn through direct experience with practical processes. In the context of mathematics, simulations usually involve presenting everyday problems that must be solved by applying mathematical concepts. Examples include arranging geometric layouts, planning travel routes, and managing the composition of food ingredients.

Adventure games are also widely used in mathematics learning, particularly for managing cognitive load. These adventure games involve completing specific missions by applying mathematical concepts. In these games, players assume the role of a main character tasked with exploring a virtual world. Players must overcome various challenges or complete missions by utilizing their mathematical abilities.

Puzzle and role-playing game genres appear to be less frequently adopted for reducing cognitive load in mathematics learning (Figure 7). Puzzle games in mathematics are similar to general puzzle games, but solving the puzzle requires the application of basic mathematical concepts. Examples include puzzles that involve arranging flat shapes or assembling images that involve fractions, and so on. Meanwhile, role-playing games in mathematics focus on players being required to take on specific roles or characters, such as a seller and buyer, an architect, a farmer, and so on.

Game Genres Used to Reduce Cognitive Load in Mathematics Learning on Different Content. Various types of games are used to reduce cognitive load in mathematics learning. The following are the game genres and mechanisms used according to the category of mathematics learning content:

Table 2. Strategies for Reducing Cognitive Load Based on Content Material

Content	Game Genre	Mechanism
Algebra	Simulation	Using the Geogebra and Scratch applications to visualize the exterior angles of a pentagon and rotations using specific variables (algebraic equations). (Fang et al., 2025)
	Quiz	Providing several questions related to algebra with several levels. (Xiang et al., 2025)
Arithmetic	Simulation	A digital game that provides a simulation for weighing items by applying the principles of addition and subtraction. (Liao et al., 2019)
	Role Play	A digital game set in a house with two main characters who ask each other questions to determine the number of components needed to repair the house by applying the concepts of addition and subtraction. (Zhong, 2022)
	Quiz	A quiz game that provides story questions related to addition and subtraction. (Karabay & Meşe, 2024)
	Adventure	Players take on the role of a prince who must complete missions to save his kingdom. The missions involve defeating enemies and overcoming challenges by solving math problems involving addition and subtraction. (Chu et al., 2021)
Number Line	Quiz	A game with several questions related to number lines to win prizes. (Smyrnis et al., 2022)
Geometry	Simulation	Simulation of making a lock by applying the principles of spatial construction. (Wang et al., 2024) Simulation of solving problems related to building houses by applying geometric principles. (Shi et al., 2023)
	Puzzle	Combining pieces of flat shapes (Chen & Huang, 2023)
	Quiz	A spatial quiz game that provides several questions with specific scores. (Miller-Cotto & Medrano, 2025).
Graphs	Quiz	A quiz game that provides several puzzle questions related to reading data in graphs and interpreting their contents. (Jhang et al., 2025)
Percentages	Quiz	A quiz game that provides questions related to everyday problems that can be solved using percentage calculations. (Weijer-Bergsma & Ven, 2021)
Patterns	Simulation	A simulation game where you mix certain ingredients to produce specific colors by following the provided instructions. (Cho et al., 2022).

	Adventure	A pirate adventure game that takes you around the seas with several missions with specific pattern clues. (Huang et al., 2023).

Table 3 shows that each mathematics concept is taught using specific game genres to manage cognitive load during learning. Algebra concepts in several studies were taught using simulation games and quizzes. Arithmetic concepts were taught using a more diverse range of game genres, namely simulations, role-playing games, quizzes, and adventure games. The number line concept was taught using quizzes to manage the cognitive load. Geometry concepts were taught using simulations, puzzles, and quizzes. Quizzes were also used to teach concepts related to graphs and percentages. Finally, pattern concepts were taught through simulations and adventure games. Overall, quizzes were the most adopted game genre across all types of mathematics concepts based on the analyzed research.

The Influence of DGBL on Cognitive Load in Mathematics Learning

Effectiveness of DGBL in Reducing Cognitive Load in Mathematics Learning

The assumption of heterogeneity in this article is made by examining the I^2 value from the meta-analysis testing. The results are as follows:

Table 3. Heterogeneity Calculation Results

Tau	Tau²	I²	H²	R²	df	Q	p
0.383	0.1464 (SE= 0.0792)	71.9%	3.558	.	14.000	49.784	<.001

The I^2 value is 71.9%, which is greater than 50%, thus demonstrating significant heterogeneity. This indicates that a random-effects model should be used when making decisions about the effectiveness of DGBL (Digital Game-Based Learning) on reducing cognitive load. The effectiveness of DGBL in reducing cognitive load is assessed by calculating Hedges' g effect size, examining the SMD (Standardized Mean Difference) values in the following table.

Table 4. Effect Size of DGBL in Reducing Cognitive Load

SDM	95%-CI	z	p-value
-0.6206	[-0.8532; -0.3880]	-5.23	< 0.0001

Hedges's g was -0.6206 (Table 5), indicating a medium effect size with a negative value. This negative value signifies that the experimental group exhibited a lower cognitive load compared to the control group. Therefore, the use of DGBL in mathematics learning effectively reduced cognitive load during the learning process. The medium effect size suggests a moderate impact of DGBL on cognitive load reduction. The 95% confidence interval (CI) of [-0.8532, -0.3880] did not cross zero, indicating a statistically significant effect. This significance is further supported by a p-value of 0.0106. A z-value of 5.23, which is greater than 1.96, demonstrates a significant difference in cognitive load between the control and experimental groups. Thus, the use of DGBL is proven to be both effective and significant in reducing cognitive load during mathematics learning.

Factors Influencing the Effectiveness of DGBL in Reducing Cognitive Load in Mathematics Learning

The magnitude of the effect of DGBL in reducing cognitive load during mathematics learning is influenced by several factors. These factors are observed through the moderating effects of several moderator variables. Synthesis of several studies indicates the following influential factors:

Table 5. Moderating Factors

Moderating factors	Q	d.f	p-value
Content	15.22	6	<0.0001
Game Genre	23.92	4	<0.0001

The type of mathematical content, based on Table 6, shows a Q value of 15.22 with a p-value < 0.0001, meaning that the type of content influences the magnitude of the effect of DGBL (Digital Game-Based Learning) on reducing cognitive load. The Q value indicates a significant difference in the mean between the experimental and control groups. The d.f (degrees of freedom) value of 6 indicates that there were 7 content groups (df + 1) analyzed. Furthermore, the game genre also shows similar results, with a Q value of 23.92 and a p-value < 0.0001, which means that the use of different game genres will affect the magnitude of the effect that DGBL provides in reducing cognitive load in mathematics learning. The d.f value of 4 indicates that the number of game genre categories analyzed was 5.

Optimal DGBL Strategies for Content and Game Genre Selection

The Most Effective Types of Mathematical Content for Teaching with DGBL in the Context of Reducing Cognitive Load

DGBL (Digital Game-Based Learning) has varying effects depending on the type of content being taught. This can be seen in the following table:

Table 6. Effect Size Based on Type of Math Content

Math Content	k	SMD	95% CI	τ^2	τ
Algebra	2	-1.2441	[-1.8125; -0.6757]	0.1022	0.3198
Percentages	1	-0.0915	[-0.4218; 0.2389]	0	0
Patterns	2	-0.6799	[-1.6124; 0.2527]	0.3854	0.6208
Arithmetic	4	-0.3761	[-0.7089; -0.0434]	0.0631	0.2512
Geometry	4	-0.7500	[-1.1155; -0.3845]	0.0502	0.2241
Graphs	1	-0.5987	[-1.1843; -0.0130]	0	0
Number lines	1	-0.4045	[-0.7771; -0.0318]	0	0

Table 7 demonstrates the effect of Digital Game-Based Learning (DGBL) on reducing cognitive load across different mathematics content areas. The results indicate that DGBL is highly effective in lowering cognitive load for algebra, with a Standardized Mean Difference (SMD) of -1.2441 and a 95% confidence interval that does not cross zero. Geometry is another subject where DGBL proves substantial and significant in reducing cognitive demands, yielding an SMD of -0.7500. DGBL also significantly lowers cognitive load for graphs (SMD -0.5987) and number lines (SMD -0.4045), with number lines being particularly well-suited for this approach. Furthermore, DGBL shows promise in reducing cognitive load for arithmetic content, supported by an SMD of -0.3761 and a 95% confidence interval that excludes zero. In contrast, DGBL exhibits minimal and statistically insignificant effects on reducing cognitive load for pattern-related [-1.6124; 0.2527] and percentage-based content. Overall, the findings highlight the considerable potential of DGBL in alleviating cognitive demands across various mathematics topics, especially for algebra and geometry. Overall, DGBL demonstrates a substantial and statistically significant effect on reducing cognitive load when learning algebra compared to other mathematical areas.

Most Effective Game Genres for Reducing Cognitive Load in Mathematics Learning

The effect of Digital Game-Based Learning (DGBL) on reducing cognitive load is influenced by the game genre employed. Based on the game genre, the effects can be seen in the following table:

Table 7. Effect Size Based on Game Genre

Game Genre	k	SMD	95% CI	τ^2	τ
Simulation	5	-1.0987	[-1.4327; -0.7646]	0.0552	0.2349
Quiz	6	-0.4237	[-0.6729; -0.1745]	0.0449	0.2119
Puzzle	1	-1.0250	[-1.4681; -0.5819]	0	0
Role Play	1	-0.1762	[-0.6100; 0.2576]	0	0
Adventure	2	-0.1919	[-0.4960; 0.1122]	0	0

Table 8 shows that there are 5 categories of game genres analyzed, namely Simulation, Quiz, Puzzle, Role Play, and Adventure. From the data, the Simulation genre has the greatest effect in reducing cognitive load, with a standardized mean difference (SMD) of -1.0987 and a 95% confidence interval that does not cross zero [-1.4327; -0.7646]. The relatively high SMD value compared to other game genres indicates that simulation is the most effective game genre for reducing students' cognitive load in mathematics learning. Another game genre that is quite effective in reducing cognitive load is puzzle, with an SMD value of -1.0250 and a 95% confidence interval within the range of [-1.4681; -0.5819], which does not cross zero, thus proving its significance. DGBL (Digital Game-Based Learning) with the quiz genre has also proven to be effective and significant in reducing cognitive load during learning, as evidenced by an SMD value of -0.4237, which is considered significant given that the 95% confidence interval does not cross zero [-0.6729; -0.1745].

Meanwhile, other game genres such as Role-Playing Games have a small (SMD = -0.1762) and non-significant impact on cognitive load (95% CI [-0.6100; 0.2576]), which means that role-playing games do not have a significant effect on reducing cognitive load in mathematics learning. The adventure genre has the smallest effect (-0.1919) and is also non-significant [95% CI -0.4960; 0.1122]. Overall, the most effective game genres for reducing cognitive load in mathematics learning are simulation, followed by puzzle, and then quiz games.

DISCUSSION

The synthesis of several studies indicates that the use of Digital Game-Based Learning (DGBL) in mathematics education to reduce cognitive load has diverse mechanisms depending on the type of material. This aligns with the principle that the selection of learning strategies, including gamification, should be tailored to the context of the material and the objectives of the learning program (Dan et al., 2024). Sometimes, a strategy that is suitable for a particular subject may not be entirely successful for all learning content within that subject (Lu et al., 2020). This is because each material possesses unique characteristics (Su, 2017). Therefore, considering the characteristics of the material is essential in determining an effective and successful teaching process.

A meta-analysis reveals a significant effect of digital game-based learning in reducing students' cognitive load in mathematics learning. The effect size found falls into the medium category, indicating that students who learn using digital games tend to experience lower cognitive load compared to students who learn through conventional methods. This is consistent with (Sweller, 2016), who emphasized the importance of working memory management through more interactive and engaging instructional design. Furthermore, Paas et al. (2003) stated that instructional efficiency can lead to a reduction in cognitive load during learning. Digital games effectively reduce unnecessary information processing, enabling students to achieve targeted competencies without overburdening their limited working memory capacity (Petko et al., 2020). Learning using game-based learning has been proven to reduce cognitive load and increase learning motivation (Metwally et al., 2024). The use of digital games in learning makes the learning environment more enjoyable and interactive (Arztmann et al., 2025). Digital games present abstract material in the form of interactive visualizations, which can help students understand difficult concepts, ultimately reducing the cognitive effort required to understand the material (Vyvey et al., 2018). Therefore, these research findings support existing findings that DGBL is proven effective in reducing cognitive load in mathematics learning.

Further moderator analysis indicates that the type of mathematical content plays a role in determining the effectiveness of DGBL (Digital Game-Based Learning). This aligns with Lange (2023), who stated that each learning content has its own difficulty, or what is referred to as intrinsic cognitive load in cognitive load theory. The effectiveness of instructional design heavily depends on task complexity (Sun & Kim, 2023). This means that the material plays a crucial role in the success of the learning process and the achievement of learning objectives.

The findings also show that DGBL has proven to be quite effective in reducing cognitive load in teaching algebra and geometry content, compared to percentage or pattern material, which has a smaller and insignificant effect. Algebra content tends to potentially generate a high cognitive load due to its abstract nature using symbols, where students must process operation rules, symbol manipulation, and an understanding of relational concepts simultaneously (Vanacore et al., 2023). When mathematical content is abstract, the interactive visualizations provided by DGBL can help students understand these concepts better (Al-Barakat et al., 2025).

In addition, DGBL is also very effective in reducing cognitive load in geometry material. Geometry content relates to spatial concepts, shapes, and relationships between geometric objects that are abstract (Shaame et al., 2020). Students must be able to imagine and manipulate geometric objects in their minds, which is not an easy cognitive ability (Oughton et al., 2024). The presence of DGBL helps visualize the shapes of geometric objects and provides students with the opportunity to interact with geometric objects, manipulate them, and see the changes that occur (McCashin et al., 2019). This reduces the cognitive load resulting from the characteristics of the material with the existence of game-based learning design (Elford et al., 2022). Research has also proven that DGBL is effective for teaching geometry material (Fang et al., 2025). This means that the existing findings are in line with previous research where very abstract material can be easily understood with the application of DGBL, so that students' cognitive load is not high.

On the other hand, the game genre also plays a role in determining the effectiveness of DGBL in reducing cognitive load. Each game genre has its own mechanisms. Different game genres have different characteristics and visualization features, which affect students' information processing in game-based learning (Dan et al., 2024). Selecting a genre that aligns with the characteristics of the math content and students' needs can enhance the benefits of DGBL in reducing cognitive load (Tlili et al., 2024). Simulation and puzzle genres show the greatest effect in reducing cognitive load, followed by quizzes, while role-playing and adventure genres do not show a significant influence. Simulations allow students to practice in authentic, real-world-like contexts, making mathematical concepts easier to understand (Seyderhelm & Blackmore, 2023). Reviews by Sevcenko et al. (2021) also highlight that players in simulation games demonstrate higher critical problem-solving abilities with lower cognitive load. In addition, puzzle games can stimulate logical thinking and structured problem-solving, thus supporting the management of cognitive load (Lu et al., 2020). Findings by Liu & Israel (2022) also show that the use of puzzles in game-based learning makes students motivated and actively involved, which leads students to be more focused and better able to process mathematical information. Consequently, students' cognitive load is not too high due to the ease of processing information.

These findings reinforce previous studies indicating that Digital Game-Based Learning (DGBL) is effective in reducing cognitive load by boosting student engagement. However, the effectiveness of DGBL varies depending on the mathematical content and the game genre employed. Therefore, the application of DGBL in mathematics education should carefully consider the alignment between the content type and the selected game genre to maximize its benefits. Moreover, this highlights that instructional designs which consider students' cognitive characteristics and learning preferences (through appropriate game genre selection) hold significant potential for improving mathematics learning effectiveness, extending beyond DGBL. In essence, personalizing learning based on an in-depth analysis of students' needs and learning styles is crucial for reducing cognitive load and enhancing learning outcomes.

CONCLUSION

This research demonstrates that the use of Digital Game-Based Learning (DGBL) in mathematics education can effectively reduce students' cognitive load. Through a meta-analysis, it was found that DGBL has a moderate effect on reducing students' cognitive load compared to traditional learning methods. Several important findings from this research are that the most effective mathematics content to teach using DGBL for reducing cognitive load is algebra and geometry, while percentage and pattern content is less effective. The game genres that are most effective for reducing cognitive load in mathematics learning are simulations and puzzles, followed by quizzes. Role-playing and adventure genres showed no significant effect.

These findings confirm that DGBL has great potential for reducing students' cognitive load in mathematics learning, but its effectiveness depends on the characteristics of the mathematical content and the game genre used. This research provides important implications for the development and application of technology-based mathematics learning to create a more effective and efficient learning environment. Teachers and developers of mathematics learning content need to consider the type of mathematical content and game genre that are most suitable so that the use of DGBL can maximize the reduction of students' cognitive load. In addition, this research also highlights the importance of instructional design that considers the complexity of the material and the characteristics of students to ensure that digital-based mathematics learning can run optimally.

This study, while providing valuable insights into the effectiveness of Digital Game-Based Learning (DGBL) in reducing cognitive load in mathematics learning, has limitations in that the number of studies is relatively small, which may limit the generalizability of the findings. Although a comprehensive search strategy was applied, it is possible that relevant studies were missed, potentially introducing selection bias. Future research is recommended to expand the meta-analysis by including a larger number of studies and exploring other factors, such as instructional design, that may moderate the influence of DGBL on cognitive load. Further research could incorporate more studies and explore other factors like instructional designs that moderate the influence of DGBL on cognitive load.

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