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REVIEW

Digital Game-Based Learning in Early Childhood and Primary Mathematics Education: A Systematic Review

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Abstract: Digital Game-Based Learning (DGBL) has emerged as a promising approach for enhancing mathematics learning across educational contexts. Although previous reviews have examined the effectiveness of digital games in mathematics education, limited attention has been devoted specifically to early childhood and primary education. This systematic review synthesises empirical studies investigating the use of DGBL in mathematics education for children up to 12 years of age. Following PRISMA guidelines, studies published between 2006 and 2024 were identified through searches in Scopus, Web of Science, and Google Scholar. After applying predefined inclusion and exclusion criteria, 103 empirical studies were selected for analysis. The findings reveal a substantial increase in research activity after 2015, with Educational Technology journals being the primary publication venue. Quantitative research designs predominated, while tablets and personal computers were the most frequently used devices. Puzzle games represented the most common game genre. The majority of studies focused on Number and Operations, followed by Algebra, Geometry, and Measurement. Results indicate predominantly positive effects on students' mathematical achievement, particularly in Number and Operations and Geometry. Furthermore, digital games were associated with improvements in motivation, attitudes towards mathematics, and collaborative learning. The review highlights the educational potential of DGBL in mathematics and identifies directions for future research and practice.

Keywords: digital game-based learning, mathematics education, early childhood education, primary education; educational games, systematic review

1 Introduction

Research demonstrates the pervasiveness of digital technology as an integral part of everyday life (Iivari et al., 2020). Across many contexts worldwide, both adults and children interact daily with digital technologies such as smartphones, tablets, and computers for educational, professional, and recreational purposes (Egard & Hansson, 2021). Within educational settings, digital technologies are increasingly integrated into teaching and learning practices. One such application is Digital Game-Based Learning (DGBL), which incorporates digital games as tools for enhancing learning experiences and educational outcomes (Tsai et al., 2012).

In educational research, digital games have frequently been utilised to explore innovative and effective teaching approaches. Evidence suggests that digital games can support learning across a variety of subject areas and contribute positively to students' social and emotional development (Anastasiadis et al., 2018). In mathematics education, DGBL has been applied to numerous learning domains, including number recognition, arithmetic operations, geometry, and problem-solving, with studies reporting positive effects on children's learning outcomes (Hussain et al., 2017; Hwa, 2018; Kubicki et al., 2015).

Several systematic reviews and meta-analyses have examined the use of digital games in mathematics education. Most of these studies have focused on K–12 populations without distinguishing between specific educational levels. Their findings generally indicate positive effects on both cognitive and affective learning outcomes. However, limited attention has been paid specifically to early childhood and primary education (Blumberg et al., 2024). Furthermore, few reviews have examined these educational stages separately while also considering the mathematical domains addressed through DGBL interventions. Therefore, the present review aims to contribute to the literature by identifying trends, synthesising findings, and highlighting the role of DGBL in mathematics education for children from early childhood to primary school age.

1.1 Aim of the Review

This review aims to investigate the role of Digital Game-Based Learning (DGBL) in mathematics education by examining empirical studies published between 2006 and 2024. In doing so, it seeks to provide educators, researchers, game developers, and policymakers with evidence regarding the characteristics, implementation, and outcomes of DGBL interventions in early childhood and primary mathematics education. By identifying research trends and synthesising findings across studies, this review contributes to a better understanding of how digital games can support mathematics learning and inform the development of effective educational practices and digital learning environments.

The research questions guiding this review are as follows:

RQ1: How has the publication of studies on DGBL in mathematics for preschool and primary education evolved over time?

RQ2: In which journal categories are studies on DGBL in mathematics for preschool and primary education most frequently published?

RQ3: Which countries have contributed most extensively to research on DGBL in mathematics for preschool and primary education?

RQ4: Which research methods are most commonly employed in studies investigating DGBL in mathematics for preschool and primary education?

RQ5: What are the most frequently used devices, game types, and mathematical learning areas in DGBL interventions for preschool and primary education?

RQ6: To what extent do the reviewed studies report impacts on students' cognitive and non-cognitive skills?

2 Theoretical Framework

The term Digital Game-Based Learning (DGBL) is commonly used to describe the integration of digital games into educational contexts. According to De Freitas (2006), educational games are defined as applications that utilise the characteristics of video and computer games to create engaging and immersive learning experiences while supporting specific learning goals and outcomes. Similarly, Ang et al. (2008) emphasised that game-based learning focuses on "learning through the game" rather than "learning to play the game". As an instructional approach, DGBL appears particularly suitable for early childhood education due to the central role of play in children's cognitive, social, and emotional development (Eberle, 2011).

The use of digital games has increased considerably during the last decade and became even more widespread during the COVID-19 pandemic (Barr & Copeland-Stewart, 2021; Lavidas et al., 2022). According to the Entertainment Software Association (ESA), approximately 76% of children play video games, while a substantial number of parents report that their children engage with educational digital games. Regarding the time devoted to digital gaming, Collins and Kavanaugh (2022) reported that children aged 5–8 years spend approximately 38 minutes per day playing digital games across different platforms, whereas children up to 12 years old spend approximately 89 minutes per day. Tablets, personal computers, smartphones, and gaming consoles are among the most frequently used devices. Popular digital games reported internationally include Fortnite, Minecraft, The Sims, Call of Duty, and Pokémon.

The need to explore innovative approaches for mathematics instruction, including DGBL, has increased partly because many students perceive mathematics as a challenging subject (Fleming, 2019). Findings from the Programme for International Student Assessment (PISA) 2018 indicated that a considerable proportion of participating countries demonstrated relatively low levels of mathematical performance (OECD, 2019). Consequently, researchers and educators have increasingly investigated alternative teaching approaches capable of supporting students' engagement and achievement in mathematics.

For the purposes of this review, the National Council of Teachers of Mathematics (NCTM) framework was adopted as the reference point for categorising mathematical learning domains. The NCTM identifies five major content standards: Number and Operations, Algebra, Geometry, Measurement, and Data Analysis and Probability (NCTM, 2000). These standards encompass the mathematical knowledge and skills expected across different educational stages (Petropoulou et al., 2024), including preschool and primary education, and therefore provide an appropriate framework for analysing the focus of DGBL interventions in mathematics.

Over the last decade, digital games have increasingly been recognised as an effective educational approach capable of supporting both cognitive and non-cognitive development. In addition to facilitating knowledge acquisition, DGBL has been associated with the development of skills such as collaboration, communication, positive attitudes towards learning, competitiveness, reduced anxiety, and increased motivation (Serrano, 2019; Fadda et al., 2021).

Several studies have reported positive effects of digital games on students' motivation and engagement. For example, Chen et al. (2021) investigated the enjoyment and goal orientation of ten-year-old Taiwanese students using a digital game entitled My-Pet-My-Quest. Their findings suggested that the quest-based design of the game enhanced students' motivation to complete learning tasks while simultaneously increasing enjoyment. Similarly, Dele-Ajayi et al. (2019) concluded that digital games have the potential to make mathematics learning more enjoyable and may help reduce mathematics anxiety by allowing students to engage with tasks in a less threatening environment.

Beyond affective outcomes, digital games have also been linked to improvements in mathematical knowledge and skills. Previous studies have reported positive learning outcomes in areas such as numeracy, geometry, and measurement through the implementation of DGBL interventions (Aladé et al., 2016; Brown & Harmon, 2013; Freina et al., 2020). These findings suggest that digital games can support both students' academic achievement and their engagement with mathematical learning.

2.1 Previous systematic reviews about DGBL and mathematics

Research examining the use of DGBL in mathematics education has resulted in a number of systematic reviews and meta-analyses. However, relatively few studies have focused specifically on preschool and primary education. Divjak and Tomi (2011) reviewed 26 studies and reported that digital games may positively influence both students' mathematical achievement and their attitudes towards mathematics. The authors suggested that educational goals can be more effectively achieved when digital games are integrated into mathematics instruction. In a meta-analysis of 33 studies, Byun and Joung (2018) examined DGBL in K–12 mathematics education and investigated, among other aspects, its effectiveness in supporting mathematics learning. Their findings indicated that although digital games often produce positive learning outcomes, their effectiveness may depend on how they are designed and implemented. Similarly, Tokac et al. (2019) analysed 24 empirical studies and reported positive effects of DGBL on students' mathematics achievement when compared with more traditional instructional approaches. Nevertheless, the authors also highlighted the existence of studies reporting mixed or non-significant results. Chen et al. (2021) reviewed 146 studies published between 1991 and 2020 that investigated game-based learning in mathematics and science education across all educational levels, from preschool to higher education. Their findings suggested that DGBL promotes active learning, supports academic achievement, and contributes to the development of higher-order thinking skills. Hussein et al. (2021) examined 43 studies focusing on DGBL in K–12 mathematics education. Their review explored knowledge acquisition, cognitive skill development, and affective outcomes. The results indicated predominantly positive effects across all three dimensions, supporting the educational potential of DGBL in mathematics learning. More recently, Erşen and Ergül (2022) analysed 80 empirical studies published between 2017 and 2021. Their findings highlighted Number and Operations as the most frequently investigated mathematical domain and quantitative research as the dominant methodological approach.

In addition to cognitive outcomes, several reviews have explored the impact of DGBL on affective and motivational variables. For example, Fadda et al. (2021) and Vankúš (2021) examined the influence of digital games on students' motivation and other affective outcomes in mathematics education. Both reviews reported generally positive effects, suggesting that DGBL can enhance students' motivation, engagement, and attitudes towards mathematics.

Although these reviews provide valuable insights into the use of DGBL in mathematics education, several gaps remain. Most reviews examine broad educational populations and do not focus specifically on preschool and primary education. Furthermore, findings are rarely presented separately for these educational levels, making it difficult to identify age-related patterns. Finally, few reviews organise their findings according to an internationally recognised mathematics framework such as the NCTM standards. Therefore, the present review seeks to address these gaps by focusing specifically on early childhood and primary mathematics education while analysing learning outcomes through the lens of the NCTM framework.

3 The Study

3.1 Data Collection

A systematic review methodology was adopted for the purposes of this study. The review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021), which provide a structured framework for identifying, screening, selecting, and analysing relevant studies. The review focused exclusively on empirical studies investigating the use of Digital Game-Based Learning (DGBL) in mathematics education within preschool and primary school settings.

3.2 Search Strategy

The literature search was conducted in April 2024 using three major sources: Scopus, Web of Science, and Google Scholar. The search included all eligible empirical studies published between January 2006 and April 2024 that investigated the use of Digital Game-Based Learning (DGBL) in mathematics education.

Following the initial search, the titles and abstracts of the retrieved studies were screened according to the predefined inclusion and exclusion criteria. Studies that did not focus on mathematics education, did not involve digital games, or were unrelated to the target age groups were excluded. Additional screening procedures were then applied to distinguish studies involving children up to 6 years old from those involving children over 6 and up to 12 years old. Studies including mixed age groups without separate reporting of results were excluded.

Subsequently, conference papers, dissertations, and other non-journal publications were removed in order to ensure the inclusion of peer-reviewed journal articles only. Finally, studies that did not investigate the use of digital games for mathematics learning or did not report cognitive learning outcomes were excluded. Following the application of all selection criteria, a total of 103 empirical studies were retained for analysis (see Figure 1).

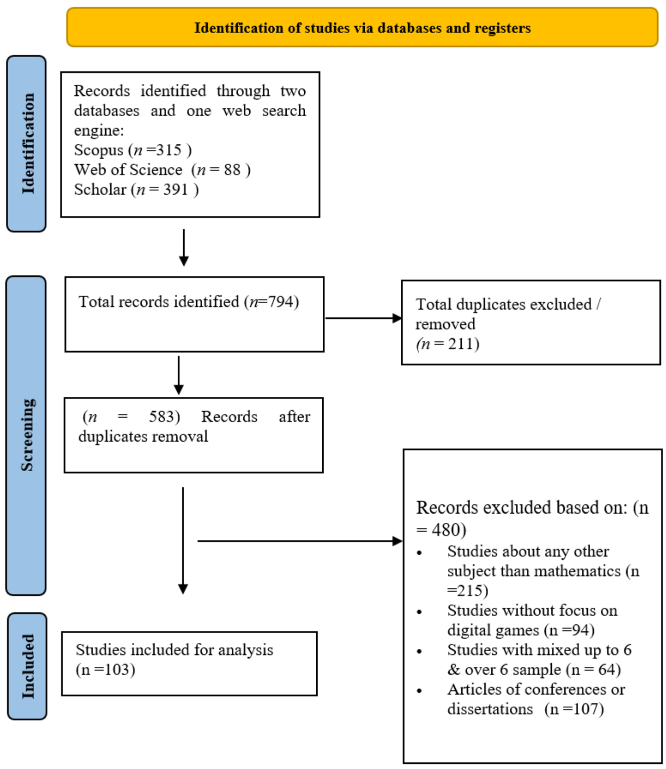

Figure 1 PRISMA flow diagram illustrating the identification, screening, eligibility assessment, and inclusion of studies in the systematic review (Page et al., 2021).

3.3 Search Terms

The search strategy was developed through a combination of Boolean operators and keywords related to digital game-based learning, mathematics education, and the target educational levels. The following search string was used: ("digital game" OR "digital game-based learning" OR "serious game") AND (preschool OR childhood OR kindergarten OR "primary education" OR "elementary education" AND NOT ("higher education" OR "special education" OR "secondary education")) AND (math*) AND TITLE (math* OR game* AND NOT (systematic OR meta* OR review OR survey OR attitudes)) AND (LIMIT-TO (LANGUAGE, "English")).

Although the same conceptual search strategy was applied across all databases, minor modifications to the search syntax and field tags were made where necessary to accommodate the specific search requirements of Scopus, Web of Science, and Google Scholar. These adaptations ensured that equivalent search concepts were applied consistently throughout the identification process while respecting the indexing features of each database.

3.4 Selection Criteria

To ensure consistency and transparency throughout the review process, a set of inclusion and exclusion criteria was established before the screening procedure (see Table 1). These criteria were designed to identify empirical studies focusing on the use of Digital Game-Based Learning for mathematics education among preschool and primary school students and to ensure the availability of sufficient methodological and contextual information for analysis.

Table 1 Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Empirical studies published between 2006 and 2024 in peer-reviewed journals.	Studies focusing on subjects other than mathematics.
Studies investigating the use of Digital Game-Based Learning (DGBL) for mathematics education.	Conference proceedings, dissertations, theses, book chapters, and other non-peer-reviewed publications.
Studies involving children up to 12 years of age, including preschool and primary school students.	Studies involving participants over 12 years of age or mixed-age samples without separate reporting of results.
Studies requiring students to actively engage with digital games.	Studies not involving student interaction with digital games.
Studies reporting cognitive mathematics learning outcomes.	Studies reporting only non-cognitive outcomes without mathematics achievement measures.
Studies addressing mathematical learning domains aligned with the National Council of Teachers of Mathematics (NCTM) framework.	Studies not specifying the mathematical learning domain addressed during the intervention.
Studies reporting sample size, country of implementation, and participants' age range.	Studies lacking essential demographic or contextual information (e.g., sample size, country, or age range).
Studies published in the English language.	Studies published in languages other than English.
Studies involving typically developing children in preschool and primary education.	Studies involving students with special educational needs.

3.5 Coding of the Studies

To ensure consistency and reliability during the coding process, a coding manual was developed prior to data extraction. The manual included detailed descriptions of all coding categories and provided guidance for the classification of studies according to the objectives of the review (Bryman, 2016).

Each study was systematically examined and coded based on the research questions guiding the review. The coding process focused on the following characteristics: (a) journal of publication, (b) year of publication, (c) participants' age range, (d) methodological approach and data collection methods, (e) geographical location of the study, (f) devices used for digital game implementation, (g) type of digital game, (h) mathematical learning domains according to the National Council of Teachers of Mathematics (NCTM) framework, and (i) reported cognitive and non-cognitive skills (see Appendices 1 and 2). The coded data were subsequently organised and analysed in order to identify publication trends, methodological characteristics, technological features, mathematical content areas, and the cognitive and non-cognitive outcomes associated with Digital Game-Based Learning interventions in mathematics education.

To enhance the transparency of the coding process, two researchers independently coded a subset of the included studies using the coding manual. The coding results were compared, and any discrepancies were discussed until consensus was reached. The agreed coding framework was subsequently applied consistently to the remaining studies.

4 Results

4.1 Type of Publication and Target Group

The selected studies were published across four major journal categories: Educational Technology (ET), General Education (GE), Mathematics Education (ME), and Psychology (PS) (Table 2). For studies involving children up to 6 years of age, Educational Technology journals accounted for 40.0% of publications, followed by General Education journals (28.9%), Psychology journals (20.0%), and Mathematics Education journals (11.1%). For studies involving children over 6 years of age, Educational Technology journals accounted for 76.4% of publications, followed by Psychology journals (10.9%), General Education journals (9.1%), and Mathematics Education journals (3.6%). Across all studies, Educational Technology journals represented 60.0% of publications, followed by General Education (18.0%), Psychology (15.0%), and Mathematics Education journals (7.0%).

Table 2 Distribution of publication types by students' age group

Publication Type	Up to 6 Years (%)	Over 6 Years (%)	Total (%)
Educational Technology (ET)	40.0	76.4	60.0
General Education (GE)	28.9	9.1	18.0
Mathematics Education (ME)	11.1	3.6	7.0
Psychology (PS)	20.0	10.9	15.0
Total	100.0	100.0	100.0

4.2 Year of Publication

Figure 2 presents the distribution of the selected studies according to publication year between 2006 and 2024. The findings indicate a gradual increase in research activity over time, with a more noticeable rise after 2015. For studies involving children up to 6 years of age, the majority of publications appeared during the last years of the examined period, with a marked increase observed from 2016 onwards. Similarly, studies involving children over 6 years of age showed increased publication activity after 2014, with publication frequencies rising further after 2017. The highest publication frequencies were observed during the latter years of the review period for both age groups.

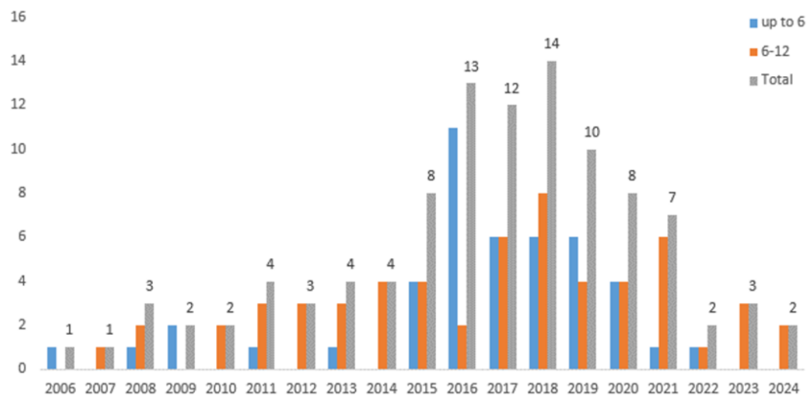

Figure 2 Distribution of studies by publication year (2006-2024)

4.3 Participants

The participants included in the reviewed studies were divided into two age groups: children up to 6 years of age attending preschool education and children over 6 years of age attending primary education. Of the 103 studies included in the review, 45 focused on preschool-aged children, whereas 58 involved primary school students. As shown in Table 3, the most frequently reported sample size category was between 51 and 100 participants, followed by studies with more than 200 participants.

Table 3 Distribution of sample sizes across studies by students' age group

Sample Size	Total (N = 103) F	Total RF (%)	Up to 6 Years (N = 45) F	Up to 6 RF (%)	Over 6 Years (N = 58) F	Over 6 RF (%)
$\leq$ 50	24	23.3	13	28.9	11	19.0
51–100	34	33.0	14	31.1	20	34.5
101–200	20	19.4	9	20.0	11	19.0
$>$ 200	25	24.3	9	20.0	16	27.6
Total	103	100.0	45	100.0	58	100.0

Note: F = frequency; RF = relative frequency.

4.4 Methodological Approach

The methodological approaches employed in the reviewed studies are presented in Table 4. Quantitative research designs were the most frequently adopted approach of all studies.

Table 4 Research methodologies employed across studies by students' age group

Research Methodology	Total (N = 103) F	Total RF (%)	Up to 6 Years (N = 45) F	Up to 6 RF (%)	Over 6 Years (N = 58) F	Over 6 RF (%)
Quantitative	84	81.6	36	80.0	48	82.8
Mixed Methods	16	15.5	7	15.6	9	15.5
Qualitative	3	2.9	2	4.4	1	1.7
Total	103	100.0	45	100.0	58	100.0

4.5 Data Collection Methods

The data collection methods employed in the reviewed studies are presented in Table 5. Tests and interviews constituted the most frequently reported data collection methods, appearing in 103 instances across the reviewed studies. Observation was reported considerably less frequently, with only nine instances identified. The same pattern appears in both age groups.

Table 5 Data collection methods used across studies by students' age group

Data Collection Method	Total (N = 103) F	Total RF (%)	Up to 6 Years (N = 45) F	Up to 6 RF (%)	Over 6 Years (N = 58) F	Over 6 RF (%)
Tests / Interviews	103	100.0	44	97.8	61	105.2
Observation	9	8.7	5	11.1	4	6.9
Total	114		49		65	

Note: Percentages may exceed 100% because a single study could be coded under more than one data collection method. F = frequency; RF = relative frequency.

4.6 Geographical Distribution

The geographical distribution of the reviewed studies is presented in Table 6. Overall, the studies were conducted across 32 different countries, spanning six continents. Overall, Europe accounted for the largest proportion of studies, followed by North America and Asia. Studies conducted in South America, Oceania, and Africa were less frequently represented. However, the distribution differed between the two age groups. Among studies involving children up to 6 years of age, North America was the most frequently reported region, followed by Europe and Asia. In contrast, among studies involving children over 6 years of age, Europe represented the largest proportion of studies, followed by North America and Asia.

Table 6 Geographical distribution of studies by students' age group

Continent	Total (N = 103) F	Total RF (%)	Up to 6 Years (N = 45) F	Up to 6 RF (%)	Over 6 Years (N = 58) F	Over 6 RF (%)
Europe	40	38.8	17	37.8	23	39.7
North America	34	33.0	20	44.4	15	25.9
Asia	22	21.4	7	15.6	14	24.1
South America	4	3.9	1	2.2	3	5.2
Oceania	2	1.9	0	0.0	2	3.4
Africa	1	1.0	0	0.0	1	1.7
Total	103	100.0	45	100.0	58	100.0

4.7 Devices Used

The devices used for Digital Game-Based Learning interventions are presented in Table 7. Overall, PCs were the most frequently used devices, followed by tablets. Other devices, such as smartphones, gaming consoles, and interactive technologies, were reported less often. Tablets were more common in studies involving children up to 6 years of age, whereas PCs were more frequently used in studies involving children over 6 years of age. Several studies used more than one device.

Table 7 Devices used in DGBL interventions by students' age group

Device	Total (N = 103) F	Total RF (%)	Up to 6 Years (N = 45) F	Up to 6 RF (%)	Over 6 Years (N = 58) F	Over 6 RF (%)
PC	54	52.4	21	46.7	33	56.9
Tablets	45	43.7	27	60.0	18	31.0
Other	11	10.7	2	4.4	9	15.5
Total	110		50		60	

Note: Percentages may exceed 100% because a single study could employ more than one device. F = frequency; RF = relative frequency.

4.8 Types of Digital Games

The digital games employed in the reviewed studies were classified into seven categories according to the framework proposed by Voulgari and Lavidas (2020): puzzle games, open-world and exploration games, simulation games, role-playing games, strategy games, card games, and other game types. he game types used in Digital Game-Based Learning interventions are presented in Table 8. Overall, puzzle games were the most frequently reported category, while simulation games and open-world and exploration games were reported less often. Other types, such as strategy games, role-playing games, card games, and other game types, were less frequently represented. Puzzle games were the dominant category in both age groups, although open-world and exploration games were more common among studies involving children up to 6 years of age, whereas simulation and strategy games appeared more often among studies involving children over 6 years of age. Several studies included more than one game type.

Table 8 Types of digital games employed across studies by students' age group

Type of Game	Total (N = 103) F	Total RF (%)	Up to 6 Years (N = 45) F	Up to 6 RF (%)	Over 6 Years (N = 58) F	Over 6 RF (%)
Puzzle Game	72	69.9	29	64.4	43	74.1
Simulation Game	14	13.6	6	13.3	8	13.8
Open-World and- -Exploration Game	13	12.6	8	17.8	5	8.6
Strategy Game	6	5.8	0	0.0	6	10.3
Role-Playing Game	3	2.9	1	2.2	2	3.4
Card Game	1	1.0	1	2.2	0	0.0
Other	3	2.9	2	4.4	1	1.7
Total	112		47		65	

Note: Percentages may exceed 100% because a single study could be classified under more than one game type. F = frequency; RF = relative frequency.

4.9 Cognitive Skills

Table 9 presents the statistically significant effects of Digital Game-Based Learning on students' mathematical cognitive skills across the NCTM mathematical domains. Overall, Number and Operations was the most frequently investigated domain and reported the highest number of statistically significant positive outcomes, followed by Algebra and Geometry. Measurement was examined less often and showed fewer significant effects. The pattern differed slightly between the two age groups. In studies involving children up to 6 years of age, Geometry showed the highest proportion of statistically significant positive outcomes, whereas in studies involving children over 6 years of age, Number and Operations showed the strongest results. No studies were identified in the domain of Data Analysis and Probability.

4.10 Non-Cognitive Skills

In addition to cognitive outcomes, several studies examined the effects of Digital Game-Based Learning on students' non-cognitive skills. Non-cognitive outcomes were reported in 30 of the

Table 9 Studies reporting significant effects of DGBL on mathematical cognitive skills by students' age group

Mathematical Domain	Total NT	Significant Effects (s)	RF (%)	Up to 6 Years NT	Significant Effects (s)	RF (%)	Over 6 Years NT	Significant Effects (s)	RF (%)
Number and Operations	85	68	80.0	40	31	77.5	45	37	82.2
Algebra	23	18	78.3	12	9	75.0	11	9	81.8
Geometry	22	17	77.3	8	7	87.5	14	10	71.4
Measurement	13	8	61.5	4	3	75.0	9	5	55.6
Data Analysis and Probability	0	0	-	-	-	-	-	-	-

Note: NT = number of studies investigating the mathematical domain; s = studies reporting statistically significant positive effects; RF = relative frequency (s/NT).

103 studies included in the review (see Appendix 2). Overall (see Table 10), attitudes towards mathematics and learning were the most frequently investigated non-cognitive outcome and showed a high proportion of statistically significant positive effects, followed by motivation and collaboration. Mathematics anxiety, competition, and communication were examined less frequently. The pattern differed between the two age groups. In studies involving children up to 6 years of age, motivation showed the strongest statistically significant positive effects, whereas in studies involving children over 6 years of age, attitudes towards mathematics were the most frequently reported outcome and demonstrated the highest proportion of statistically significant positive effects.

Table 10 Studies reporting significant effects of DGBL on non-cognitive skills by students' age group

Non-Cognitive Skill	Total NT	Significant Effects (s)	RF (%)	Up to 6 Years NT	Significant Effects (s)	RF (%)	Over 6 Years NT	Significant Effects (s)	RF (%)
Attitudes	15	13	86.7	2	1	50.0	13	12	92.3
Motivation	10	8	80.0	2	2	100.0	8	6	75.0
Collaboration	8	5	62.5	4	2	50.0	4	3	75.0
Mathematics Anxiety	4	2	50.0	–	–	–	4	2	50.0
Competition	3	0	0.0	-	-	-	3	0	0.0
Communication	1	0	0.0	-	-	-	1	0	0.0

Note: NT = number of studies investigating non-cognitive skills; s = studies reporting statistically significant positive effects; RF = relative frequency (s/NT). Some studies employed more than one non-cognitive skill.

5 Discussion

This systematic review examined empirical studies published between 2006 and 2024 that investigated the use of Digital Game-Based Learning (DGBL) in mathematics education for children attending preschool and primary school. Following the application of the inclusion and exclusion criteria, 103 studies were selected for analysis. To facilitate comparison between educational levels, the findings were examined separately for studies involving children up to 6 years of age and those involving children over 6 years of age.

Regarding publication outlets, Educational Technology journals accounted for the largest proportion of studies in both age groups. General Education journals were more frequently represented in studies involving preschool children, whereas Psychology journals appeared more often among studies focusing on primary education. Among the journals identified in the review, Computers & Education and British Journal of Educational Technology were the most frequent publication venues.

The analysis of publication years revealed a clear increase in research activity over time. Studies involving preschool children became more frequent after 2015, while research focusing on primary school students showed a notable increase after 2018. This supports previous findings reported by Hussein et al. (2021), who also identified a substantial increase in DGBL research in mathematics education during the last decade.

Regarding participants, slightly more studies focused on primary school students than on preschool children. Across both educational levels, sample sizes between 50 and 100 participants were the most common.

Concerning methodological characteristics, quantitative research designs clearly dominated the field. Only a limited number of studies adopted qualitative approaches, while mixed-methods designs were used less frequently than quantitative methods. This finding aligns with previous reviews that have also reported a strong preference for quantitative methodologies in DGBL research (Chen et al., 2021; Erşen & Ergül, 2022). In terms of data collection, achievement tests and interviews were the most commonly used instruments, often combined with pre- and post-intervention assessments. Observational methods were employed less frequently, indicating that researchers have primarily focused on measuring learning outcomes (Zourmpakis et al., 2023; Blumberg et al., 2024).

The geographical distribution of the studies showed that DGBL research in mathematics education has been concentrated primarily in Europe, North America, and Asia. Studies involving preschool children were more frequently conducted in North America, whereas research focusing on primary education was more common in European countries. Overall, the review identified studies from 32 different countries, demonstrating the international interest in the educational use of digital games. These findings are consistent with previous reviews, which reported that countries such as the United States, Taiwan, and Turkey have been among the most active contributors to research on DGBL in mathematics education (Byun & Joung, 2018; Chen et al., 2021; Divjak & Tomi, 2011).

Regarding the technological characteristics of the interventions, differences were observed between the two age groups. Tablets were more frequently used in studies involving preschool children, whereas personal computers were the preferred device in studies involving primary school students. This distinction may be associated with the developmental characteristics of younger children, for whom touch-based interfaces are generally easier to use and more intuitive. Similar findings have been reported in previous reviews, which identified personal computers and tablets as the dominant devices used in DGBL interventions (Chen et al., 2021; Erşen & Ergül, 2022; Hussain et al., 2017).

Among the game types identified in the reviewed studies, puzzle games were the most frequently used in both age groups. Open-world and exploration games appeared more frequently in studies involving preschool children, whereas simulation and strategy games were more common in studies involving primary school students. Previous reviews have similarly reported a strong presence of puzzle and simulation games within mathematics-focused DGBL interventions (Chen et al., 2021).

The predominance of puzzle games suggests that current DGBL interventions primarily emphasise mathematical problem solving and logical reasoning. At the same time, the relatively limited use of other game types indicates opportunities for future research to explore a wider range of game designs that may support different mathematical learning experiences.

With regard to cognitive outcomes, only studies reporting statistically significant effects were considered. The findings indicated that DGBL was associated with positive outcomes across several mathematical domains. For preschool children, the highest proportion of positive effects was identified in Geometry, whereas for primary school students the strongest evidence was observed in Number and Operations. Across both educational levels, Number and Operations was by far the most frequently investigated mathematical domain. This finding is consistent with previous reviews, which have also identified Number and Operations as the dominant area of interest within DGBL research in mathematics education (Byun & Joung, 2018; Erşen & Ergül, 2022; Fadda et al., 2021). No study was identified that focused on Data Analysis and Probability. This imbalance suggests that future research could broaden the range of mathematical domains addressed by DGBL interventions, particularly those that have received comparatively limited attention. Expanding research into underrepresented areas may contribute to a more comprehensive understanding of how digital games can support different aspects of mathematics learning.

In addition to cognitive outcomes, several studies examined the influence of DGBL on non-cognitive skills. The findings suggest that digital games may contribute positively to students' motivation, attitudes towards mathematics, and collaboration skills. For preschool children, motivation was the most frequently improved non-cognitive outcome, while studies involving primary school students most commonly reported positive changes in attitudes towards mathematics. These findings are in agreement with previous reviews, which have highlighted the positive contribution of DGBL to motivation and attitudes towards learning mathematics (Chen et al., 2021; Divjak & Tomi, 2011; Fadda et al., 2021; Vankúš, 2021).

6 Limitations

This review has several limitations that should be considered when interpreting the findings. First, only studies published in peer-reviewed journals and written in English were included. As a result, relevant studies published in other languages or reported in conference proceedings, dissertations, and other forms of grey literature were excluded. Second, although three major databases were searched, it is possible that some relevant studies were not identified. Third, the review focused exclusively on studies involving children up to 12 years of age, limiting the generalisability of the findings to other educational levels. Finally, the reviewed studies differed considerably in terms of research design, sample size, intervention duration, game characteristics, and outcome measures, making direct comparisons between studies challenging. Despite these limitations, the review provides a comprehensive overview of the current state of research on DGBL in early childhood and primary mathematics education and identifies important directions for future research.

7 Conclusion

This systematic review synthesised 103 empirical studies published between 2006 and 2024 that investigated the use of Digital Game-Based Learning (DGBL) in mathematics education for preschool and primary school students. The findings revealed a substantial increase in research activity during the last decade, indicating growing interest in the educational use of digital games for mathematics learning. Educational Technology journals emerged as the primary publication venue, while quantitative research designs were the most frequently employed methodological approach.

The review showed that tablets and personal computers were the most commonly used devices and that puzzle games represented the dominant game type across both educational levels. Number and Operations was the most frequently investigated mathematical domain, followed by Algebra, Geometry, and Measurement. Overall, the reviewed studies reported predominantly positive effects on students' mathematical achievement, with particularly strong evidence in Number and Operations and Geometry. In addition, positive outcomes were identified for several non-cognitive skills, including motivation, attitudes towards mathematics, and collaboration.

The findings suggest that DGBL represents a valuable approach for supporting mathematics learning in both preschool and primary education. At the same time, the limited attention devoted to certain mathematical domains, non-cognitive outcomes, and game types highlights the need for further research. Future studies should continue to explore how different game designs and instructional approaches can support diverse aspects of mathematics learning and development.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Appendix 1-1. Characteristics of the Included Studies (N = 103)

Author/Year	Title	Sample (range and age)	Research design	Digital Game	Mathematics Area	Assessment tool
Rutherford, T. et al. (2014)	Math computerized games in the classroom: A number line training in primary school children.	13803 – over 6	Pre & post tests	ST-Math	Number & operations/ geometry/ measurement	California Standards Tests (CSTs)
Bui, P. et al. (2020)	Understanding students' game experiences throughout the developmental process of the number navigation game.	1168 – over 6	Post test only – interview post	Number Navigation Game (NNG)	Number & operations/ Algebra	Game Experience Questionnaire (GEQ)
Brezovszky, B. et al. (2019)	Effects of a mathematics game-based learning environment on primary school students' adaptive number knowledge.	1168 – over 6	Pre & post test	Number Navigation Game (NNG)	Number & operations/ algebra	Paper-and-pencil measures
Rodríguez-Aflecht, G. et al. (2017)	Voluntary vs compulsory playing contexts: motivational, cognitive, and game experience effects.	1061 – over 6	Pre & post test	Number Navigation Game (NNG)	Number & operations/ Algebra	Interest and self-efficacy test, Arithmetic fluency test, Adaptive Number Knowledge (ANK) Task, Game Experience Questionnaire.
Bakker, M., van den Heuvel-Panhuizen, M., & Robitzsch, A. (2015)	Effects of playing mathematics computer games on primary school students' multiplicative reasoning ability.	719 - over 6	Pre & post test	32 mini games	Number & operations	Knowledge Test, Skills Test, Insight Test.
Miller, D. J., & Robertson, D. P. (2011)	Educational benefits of using game consoles in a primary classroom: A randomised controlled trial.	634 – over 6	Pre & post test	Dr Kawashima's Brain Training	Number & operations	100-item 'Number Challenge', Marsh's Self Description Questionnaire.
Ke, F. (2008)	Computer games application within alternative classroom goal structures: cognitive, metacognitive, and affective evaluation.	487 – over 6	Pre & post test – observation	ASTRA EAGLE	Number & operations/ geometry/measurement	36-item "Game Skills Arithmetic Test (GSAT)"
Thai, K. P., Bang, H. J., & Li, L. (2021)	Accelerating early math learning with research-based personalized learning games: A cluster randomized controlled trial.	453 – up to 6	Pre & post test	My Math Academy	Number & operations / algebra	Test of Early Mathematics Ability (TEMA-3), My Math Academy Usage Data, Teacher Survey.
Schacter, J., & Jo, B. (2017)	Improving preschoolers' mathematics achievement with tablets: A randomized controlled trial.	433 – up to 6	Pre & post test	Math Shelf	Number & operations / algebra	48-item iPad early mathematics assessment developed for the study
Gerholm, T. et al. (2019)	A randomized controlled trial to examine the effect of two teaching methods on preschool children's language and communication, executive functions, socioemotional comprehension, and early math skills.	431 – up to 6	Pre & post test	The Magical Garden	Number & operations	Language test, communication test, executive functions test, emotional comprehension test, math test.
Outhwaite, L et al. (2019)	Raising early achievement in math with interactive apps: A randomized control trial.	389 – up to 6	Pre & post test	Maths 3–5 / Maths 4–6	Number & operations/ algebra/ geometry/ measurement	Progress Test in Math- 5 (PTM5)
Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2018)	The effectiveness of computer and tablet assisted intervention in early childhood students' understanding of numbers. An empirical study conducted in Greece.	365 – up to 6	Pre & post test	32 Digital games created by researchers.	Number & operations	Test of Early Mathematics Ability (TEMA-3)
Fraga-Varela, F., Vila-Couñago, E., & Rodríguez-Groba, A. (2021)	Serious Games and Mathematical Fluency: A Study from the Gender Perspective in Primary Education.	284 – over 6	Pre & post test	ReflexMath	Number & operations	Basic Math Operations Task (BMOT)
Hassler Hallstedt, M., Klingberg, T., & Ghaderi, A. (2018)	Short and long-term effects of a mathematics tablet intervention for low performing second graders.	283 – over 6	Pre & post test	Chasing Planets	Number & operations	Math Battery scales, HRT Addition, Subtraction, and Missing Term, Klurisen, HRT Count Amount, Ravens, the Arithmetic Composite, Grid, and DigitSpan
O'Rourke, J., Main, S., & Hill, S. (2017)	Commercially available digital game technology in the classroom: Improving automaticity in mental-maths in primary-aged students.	278 – over 6	Pre & post test – pre & post interview – observation	Dr Kawashima's Brain Training	Number & operations	One Minute Test of Basic Number Facts

Appendix 1-2. Characteristics of the Included Studies (N = 103)

Schacter, J., & Jo, B. (2016)	Improving low-income preschoolers mathematics achievement with Math Shelf, a preschool tablet computer curriculum.	273 – up to 6	Pre & post test	Math Shelf	Number & operations/ algebra	44-item iPad early mathematics assessment was developed for the study
Beserra, V., Nussbaum, M., Zeni, R., Rodriguez, W., & Wurman, G. (2014)	Practising arithmetic using educational video games with an interpersonal computer.	271 – over 6	Pre & post test – observation	Not reported	Number & operations	paper instruments
Foster, M. E. et al. (2018)	Hispanic dual language learning kindergarten students' response to a numeracy intervention: A randomized control trial.	270 – up to 6	Pre & post test	Building Blocks	Number & operations/ Geometry	Research-based Early Maths Assessment (REMA), Expressive One Word Picture Vocabulary Test (EOWPVT), Applied Problems subtest of the Woodcock-Johnson III Tests of Achievement.
Gómez, F. et al. (2013)	Co-located single display collaborative learning for early childhood education.	268 – up to 6	Pre & post test	RoleGame / Sort / Exchange	Number & operations	Two tests: one for oral language and logical-mathematical rand quantification, and another for social skills.
Volk, M., Cotič, M., Zajc, M., & Starcic, A. I. (2017)	Tablet-based cross-curricular maths vs. traditional maths classroom practice for higher-order learning outcomes.	259 – over 6	Pre & post test	Clock app / Grid app / Map app	Geometry/measurement	Pre-post participation tests.
Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016)	Comparing tablets and PCs in teaching mathematics: An attempt to improve mathematics competence in early childhood education.	256 – up to 6	Pre & post test	32 apps drill & practice	Number & operations	Test of Early Mathematics Ability–Third Edition (TEMA3).
Kolovou, A., van den Heuvel-Panhuizen, M., & Köller, O. (2013)	An intervention including an online game to improve grade 6 students' performance in early algebra.	236 – over 6	Pre & post test	Hit the Target	Algebra	Early Algebra test, End Grade 5 Cito-LOVS Mathematics test (Cito E5 test)
Fokides, E. (2018)	Digital educational games and mathematics. Results of a case study in primary school settings.	201 – over 6	Pre & post test	Kodu Game Lab	Number & operations	Test and questionnaire
Silander, M. et al. (2016)	Using Digital Media at Home to Promote Young Children's Mathematics Learning: Results of a Randomized Controlled Trial.	197 – up to 6	Pre & post test	PBS KIDS (PEG+CAT)	Number & operations/ algebra/ geometry	Assessment test
Moyer-Packenham, P. S. et al. (2019)	How design features in digital math games support learning and mathematics connections.	193 – over 6	Pre & post test	12 digital math games	Number & operations/ geometry	Assessment test
Hulse, T. et al. (2019)	From here to there! Elementary: a game-based approach to developing number sense and early algebraic understanding.	185 - over 6	Pre & post test	From Here to There!	Algebra	Worksheets and in-app data logs
Aragón-Mendizábal, E. et al. (2017)	Improving number sense in kindergarten children with low achievement in mathematics.	156 – up to 6	Pre & post test	Playing with Numbers 2.0	Number & operations/ algebra	Early Numeracy Test Revised (ENT- R)
Ramani, G. B. et al. (2019)	Racing dragons and remembering aliens: Benefits of playing number and working memory games on kindergartners' numerical knowledge.	148 – up to 6	Pre & post test	The Great Race / Recall Them All	Number & operations	Mathematical knowledge measures
Beşaltı, M., & Ümit, K. U. L. (2021)	Effects of a Game-Based app on Primary Students' Self Efficacy and Achievements in Learning Fractions During Distance Education.	142 – over 6	Pre & post test	Slice Fractions	Number & operations	Trends in International Mathematics and Science Study (TIMMS), Self-efficacy Scale
Outhwaite, L. A., Gulliford, A., & Pitchford, N. J. (2017)	Closing the gap: Efficacy of a tablet intervention to support the development of early mathematical skills in UK primary school children.	133 – up to 6	Pre & post test	4 apps	Number & operations/ geometry	similar to the Numerical Operations sub-test of the WIAT-II
Kim, H., & Ke, F. (2017)	Effects of game-based learning in an OpenSim-supported virtual environment on mathematical performance.	132 – over 6	Pre & post test	OpenSim-supported VR learning environment	Number & operations	Assessment test
Ke, F., Grabowski, B. (2007)	Game playing for mathematics learning: cooperative or not?	125 – over 6	Pre & post test	ASTRA EAGLE	Number & operations/ geometry/ measurement	Game Skills Arithmetic Test (GSAT)

Appendix 1-3. Characteristics of the Included Studies (N = 103)

McManis, M. H., & McManis, L. D. (2016)	Using a Touch-Based, Computer-Assisted Learning System to Promote Literacy and Math Skills for Low-Income Preschoolers.	125 – up to 6	Pre & post test	iStartSmart learning system	Number & operations/algebra/geometry	Bracken School Readiness Assessment, Test of Preschool Early Literacy (TOPEL)
Riconscente, M. M. (2013)	Results from a controlled study of the iPad fractions game Motion Math.	122 – over 6	Pre & post test	Motion Math	Number & operations	National Assessment of Educational Progress (NAEP), Trends in International Mathematics and Science Study
Lee, H. K., & Choi, A. (2020)	Enhancing early numeracy skills with a tablet-based math game intervention: a study in Tanzania.	122 – over 6	Pre & post test	Kitkit™ School	Number & operations	Early Grade Mathematics Assessment (EGMA)
Zaranis, N., & Valla, V. (2019)	Tablets in learning mathematics for kindergarten students.	118 – up to 6	Pre & post test	KTMM	Number & operations	Early Numeracy Test (ENT)
Weiss, I., Kramarski, B., & Talis, S. (2006)	Effects of multimedia environments on kindergarten children's mathematical achievements and style of learning.	116 – up to 6	Pre & post test	Goldilocks series games	Number & operations	mathematical achievement tests, attitudes questionnaire
Wang, S. Y. et al. (2018)	A microworld-based role-playing game development approach to engaging students in interactive, enjoyable, and effective mathematics learning.	107 – over 6	Pre & post test	Speedy World	measurement	Learning performance tests, questionnaires of learning motivation
Park, J. et al. (2016)	Non-symbolic approximate arithmetic training improves math performance in preschoolers.	103 – up to 6	Pre & post test	approximate arithmetic group training game / Picture memory training game	Number & operations	Test of Early Mathematical Achievement–Third Edition (TEMA-3)
van der Ven, F. et al. (2017)	Effects of a tablet game intervention on simple addition and subtraction fluency in first graders.	103 – over 6	Pre & post test	Not reported	Number & operations	arithmetic test
Lakshmi, D., & Ponnusamy, R. (2021)	Working memory enhancement during early childhood based on the utilization of interactive gesture game-based learning.	100 – over 6	Pre & post test	Not reported	Number & operations	Corsi Blocking-Tapping test, backward Corsi Blocking-Tapping test, Forward Digit Span test, Digit Span test
Schenke, K. et al. (2020)	Does "Measure Up!" measure up? Evaluation of an iPad app to teach preschoolers measurement concepts.	99 – up to 6	Pre & post test	PBS Kids Measure Up!	Number & operations	20-item assessment
Jay, T. et al. (2019)	Game-based training to promote arithmetic fluency.	97 – over 6	Pre & post test	Raiding	Number & operations	Westwood 1-min basic facts tests
Sýkora, T., Stárková, T., & Brom, C. (2021)	Can narrative cutscenes improve home learning from a math game? An experimental study with children.	95 – over 6	Pre & post test	Matemág	Number & operations/ measurement	Parents & children questionnaire, knowledge test, near transfer test
Shin, N. et al. (2012)	Effects of game technology on elementary student learning in mathematics.	91 – over 6	Pre & post test – observation / post test only	Skills Arena	Number & operations	70-item assessment test
Soydan, S. (2015)	Analyzing efficiency of two different methods involving acquisition of operational skills by preschool children.	90 – up to 6	Pre & post test	Not reported	Number & operations	Assessment test
Peralbo-Uzquiano, M. et al. (2020)	Evaluation of the effects of a virtual intervention programme on cognitive flexibility, inhibitory control and basic math skills in childhood education.	90 – up to 6	Pre & post test	Not reported	Number & operations/ algebra/ geometry	Test for Diagnosis Assessment of Mathematical Disabilities (TEDI-MATH)
Szkudlarek, E., & Brannon, E. M. (2018)	Approximate arithmetic training improves informal math performance in low achieving preschoolers.	86 – up to 6	Pre & post test	Max's Math / 123 Ninja	Number & operations	symbolic math test based on the Number Sense Screener (NSS), short-term memory task, a Stroop interference task, a standard dimensional card sorting task, the Peabody Picture Vocabulary Test 4th Edition (PPVT-4
McCarthy, E., Tiu, M., & Li, L. (2018)	Learning math with curious George and the odd squad: Transmedia in the classroom.	83 – over 6	Pre & post test – interview post	Odd Squad	Number & operations/algebra	Test of Early Mathematical Achievement–Third Edition (TEMA-3)
Chen, Y. H. et al. (2012)	A Collaborative Cross Number Puzzle Game to Enhance Elementary Students' Arithmetic Skills.	83 – over 6	Pre & post test	Cross Number Puzzle	Number & operations	Assessment of arithmetic skill ability

Appendix 1-4. Characteristics of the Included Studies (N = 103)

Beserra, V., Nussbaum, M., & Grass, A. (2017)	Using a fine-grained multiple-choice response format in educational drill-and-practice video games.	83 – over 6	Pre & post test	Not reported	Number & operations	Assessment test
Freina, L., Bottino, R., & Ferlino, L. (2018)	Visuospatial abilities training with digital games in a primary school.	79 – over 6	Pre & post test	"A me gli occhi"project	Geometry	AC-MT 6-11
Vanbecelaere, S. et al. (2021)	The effectiveness of an adaptive digital educational game for the training of early numerical abilities in terms of cognitive, noncognitive and efficiency outcomes.	78 – over 6	Pre & post test	Number Sense Game	Number & operations	"pictorial calculation" and "simple arithmetic" subtest of the TEDI-MATH, Kinder-Angst-Test-III (KAT-III)
Rocha, M., & Dondio, P. (2021)	Effects of a videogame in math performance and anxiety in primary school.	73 – over 6	Pre & post test – interview post	Once Upon A Maths	Number & operations/ algebra/ geometry/ measurement	Math questionnaire, modified Abbreviated Mathematics Anxiety Scale (mAMAS).
Gecu-Parmaksiz, Z., & Delialioglu, O. (2019)	Augmented reality-based virtual manipulatives versus physical manipulatives for teaching geometric shapes to preschool children.	72 – up to 6	Pre & post test	AR app	geometry	Geometric Shape Recognition Task
Lin, Y. H., & Hou, H. T. (2016)	Exploring young children's performance on and acceptance of an educational scenario-based digital game for teaching route-planning strategies: a case study.	71 – up to 6	Pre & post test – interview post	I am a Zoo Player	Geometry	Worksheet
Miller, D. J., & Robertson, D. P. (2010)	Using a games console in the primary classroom: Effects of 'Brain Training'programme on computation and self-esteem.	71 – over 6	Pre & post test	Dr Kawashima's Brain Training	Number & operations	100-item test (the 'Number Challenge')
Es-Sajjade, A., & Paas, F. (2020)	Educational theories and computer game design: lessons from an experiment in elementary mathematics education.	70 – over 6	Post test only	Matherial	Algebra	written math test
McCarthy, E., Tiu, M., & Li, L. (2018)	Learning math with curious George and the odd squad: Transmedia in the classroom.	68 – up to 6	Pre & post test – interview post – observation	Curious George	Number & operations	Test of Early Mathematical Achievement–Third Edition (TEMA-3)
Hung, C. M., Huang, I., & Hwang, G. J. (2014)	Effects of digital game-based learning on students' self-efficacy, motivation, anxiety, and achievements in learning mathematics.	68 – over 6	Pre & post test – interview post	game-based e-books	Geometry	Two tests (one pre test & one post test) developed by teachers, self-efficacy scale, learning motivation scale, and mathematical anxiety scale
Akman, E., & Çakır, R. (2020)	The effect of educational virtual reality game on primary school students' achievement and engagement in mathematics.	64 – over 6	Pre & post test – observation	Keşfet Kurtul	Number & operations	academic achievement test (AAT), Student engagement in mathematics scale (SEMS)
Kermani, H. (2017)	The effect of educational virtual reality game on primary school students' achievement and engagement in mathematics.	62 – up to 6	Pre & post test	10 computer games	Number & operations/ algebra	Test of Early Mathematical Achievement–Third Edition (TEMA-3)
Lin, C. H. et al (2011)	Game-based remedial instruction in mastery learning for upper-primary school students.	62 – over 6	Pre & post test	Monopoly	Geometry	written assessment
Räsänen, P. et al. (2009)	Computer-assisted intervention for children with low numeracy skills.	60 – up to 6	Pre & post test	The Number Race / Graphogame-Math	Number & operations	four tasks of number skills, verbal and spatial working memory
Alzubi, T. et al. (2018)	Improving the working memory during early childhood education through the use of an interactive gesture game-based learning approach.	60 – up to 6	Pre & post test	Capture fish /Abacus. /The chair and advance chair. /Counting by jumping. /Order number. /Inside-outside class. /Scuba diving. /Toy dolls	Number & operations	TEDI-MATH
Sung, Y.-T., Chang, K.-E., & Lee, M.-D. (2008)	Designing multimedia games for young children's taxonomic concept development.	60 – up to 6	Pre & post test	SoRT: the software for rebuilding taxonomy / My First Math Adventure – Counting and Classification / Toby's IQ Training Camp – the Seed of Logic	Algebra	Classifying colored geometric tiles test (CCGTT)

Appendix 1-5. Characteristics of the Included Studies (N = 103)

Aladé, F. et al. (2015)	Measuring with Murray: Touchscreen technology and preschoolers' STEM learning.	60 – up to 6	Pre test only	Measure the animal	Measurement	Picture Naming Individual Growth and Development Indicator, knowledge transfer tasks.
Pope, H., & Mangram, C. (2015)	Wuzzit trouble: The influence of a digital math game on student number sense.	59 – over 6	Pre & post test	Wuzzit Trouble	Number & operations	paper-and-pencil assessment
Main, S., & O'Rourke, J. (2011)	'New directions for traditional lessons': Can handheld game consoles enhance mental mathematics skills?	59 – over 6	Pre & post test	Dr Kawashima's Brain Training	Number & operations	Westwood One Minute Test of Basic Number Facts, Mathematical Self-Concept scale
Yang, K. H., Chu, H. C., & Chiang, L. Y. (2018)	Effects of a progressive prompting-based educational game on second graders' mathematics learning performance and behavioral patterns.	58 – over 6	Pre & post test	Kingdom of Addition and Subtraction	Number & operations	questionnaires of flow experience, mathematics self-efficacy and test of two-steps addition-subtraction
Huang, Y. M., Huang, S. H., & Wu, T. T. (2014)	Embedding diagnostic mechanisms in a digital game for learning mathematics.	56 – over 6	Pre & post test – interview post	1 digital game	Number & operations	Assessment test. mathematics anxiety scale
Wang, F. et al (2016)	Using touchscreen tablets to help young children learn to tell time.	56 – up to 6	Pre & post test	Interactive Telling Time	Measurement	iPad Touchscreen Test Apparatus, Toy Clock Test Apparatus, Paper Test Apparatus
Wilson, A. J. et al. (2009)	Effects of an adaptive game intervention on accessing number sense in low-socioeconomic-status kindergarten children.	53 – up to 6	Pre & post test	The Number Race	Number & operations	paper and pencil and verbal tests
Castellar, E. N. et al. (2015)	Cognitive abilities, digital games and arithmetic performance enhancement: A study comparing the effects of a math game and paper exercises.	52 – over 6	Pre & post test – interview post	Monkey Tales	Number & operations	Assessment test, Digit Span subtest of the WISC-III NL, Mazes subtest of the WISC-III NL
Mohd Syah, N. E. et al. (2016)	Development of computer play pedagogy intervention for children with low conceptual understanding in basic mathematics operation using the dyscalculia feature approach.	50 – over 6	Pre & post test	Math.ACE	Number & operations	Assessment test
Kim, N., Jang, S., & Cho, S. (2018)	Testing the efficacy of training basic numerical cognition and transfer effects to improvement in children's math ability.	46 – over 6	Pre & post test	123 Bakery	Number & operations	Comprehensive math achievement test (KNISE-BAAT), Computerized arithmetic task,
Sella, F. et al. (2016)	Training numerical skills with the adaptive videogame "The Number Race": A randomized controlled trial on preschoolers.	45 – up to 6	Pre & post test	Number Race	Number & operations/ measurement	The Numerical Intelligence Battery-BIN, Number line tasks, AC-MT battery
Schroeder, E. L., & Kirkorian, H. L. (2016)	When seeing is better than doing: Preschoolers' transfer of STEM skills using touchscreen games.	44 – up to 6	Pre & post test	Mesozoic Math Adventures	Number & Operations	Assessment test, near/far transfer test
Pareto, L. et al. (2012)	A teachable-agent-based game affording collaboration and competition: Evaluating math comprehension and motivation.	38 – over 6	Pre & post test	Teachable agents	Number & operations	Math comprehension test, Attitude questionnaire, interview about collaboration and competition.
Bullock, E. P. et al. (2017)	Affordance access matters: Preschool children's learning progressions while interacting with touch-screen mathematics apps.	35 – up to 6	Pre & post interview	Pink Tower / Red Rods / base-10 blocks	Number & operations/ algebra	Clinical interviews
Yang, J. C., & Chen, S. Y. (2010)	Effects of gender differences and spatial abilities within a digital pentominoes game.	34 – over 6	Pre & post test	digital pentominoes game	Geometry	Spatial Intelligence Scale, spatial ability test
Tucker, S. I. et al. (2017)	Kindergarten Children's Interactions with Touchscreen Mathematics Virtual Manipulatives: An Innovative Mixed Methods Analysis.	33 – up to 6	Interview post – observation	Hungry Guppy: 4-dot and 5-dot Fish / Fingu: Levels 1 and 2 / Friends of Ten: How Many More (10 Frame) / Montessori Numbers: Math Activities for Kids: Quantity 10-99; 1 to 20: 11- 20; & Numerals.	Number & operations	Assessments based on Quantity in Base Ten/ Early Number Sense
Käser, T. et al. (2013)	Design and evaluation of the computer-based training program Calcularis for enhancing numerical cognition.	32 – over 6	Pre & post test	Calcularis	Number & operations	Heidelberger Rechentest (HRT), computer-based mathematical tests, feedback questionnaire

Appendix 1-6. Characteristics of the Included Studies (N = 103)

Baccaglini-Frank, A., & Maracci, M. (2015)	Multi-touch technology and preschoolers' development of number-sense.	25 – up to 6	Observation	Ladybug Count / Fingu	Number & operations	Video analysis
Mattoon, C. et al. (2015)	Examining computational skills in Prekindergarteners: The effects of traditional and digital manipulatives in a prekindergarten classroom.	24 – up to 6	Pre & post test	DinoKids / Hungry Fish / Math Express / Maths, age 3–5 / Park Math.	Number & operations	Test of Early Mathematics Ability— Third Edition (TEMA3).
Fischer, U. et al. (2011)	Sensori-motor spatial training of number magnitude representation.	22 – up to 6	Pre & post test	Dance Mat	Number & operations	TEDI-MATH
Çakıroğlu, Ü. & Taşkın, N. (2016)	Teaching numbers to preschool students with ınteractive multimedia: An experimental study .	20 – up to 6	Pre & post test	IMLE (Interactive Multimedia Learning Environment)	Number & operations	Piaget's Conservation of Number Test (PCNT)
Hwa, S. P. (2018)	Pedagogical change in mathematics learning: Harnessing the power of digital game-based learning.	20 – over 6	Pre & post test	DigiGEMs	Number & operations/ geometry	Assessment test
Baccaglini-Frank, A., Carotenuto, G., & Sinclair, N. (2020)	Eliciting Preschoolers' Number Abilities Using Open, Multi-Touch Environments.	19 – up to 6	Pre test only	TouchCounts	Number & operations	Interview to select the participating children
Tucker, S. I., & Johnson, T. N. (2020)	Developing number sense with Fingu: a preschooler's embodied mathematics during interactions with a multi-touch digital game.	18 – up to 6	Observation	Fingu	Number & operations	Video analysis
Zhang, M. et al. (2015)	Using math apps for improving student learning: An exploratory study in an inclusive fourth grade classroom.	18 – over 6	Pre & post test	Splash Math / Motion Math Zoom / Long Multiplication	Number & operations	paper and pencil tests
Broda, M. et al. (2019)	Small fingers, big data: Preschoolers' subitizing speed and accuracy during interactions with multitouch technology.	18 – up to 6	Observation	Fingu	Number & operations	None
Salminen, J. et al. (2015)	Preventive support for kindergarteners most at-risk for mathematics difficulties: Computer-assisted intervention.	17 – up to 6	Pre & post test	GraphoGame Math / Number Race	Number & operations	Corsi blocks task, Nonword repetition task, Early Numeracy Test and paper & pencil test
Ke, F. (2008)	A case study of computer gaming for math: Engaged learning from gameplay?.	15 = over 6	Pre & post test – observation	ASTRA EAGLE	Number & operations/ algebra/ geometry/mea-surement	'Game Skills Arithmetic Test (GSAT)
Kyriakides, A. O., Meletiou-Mavrotheris, M., & Prodromou, T. (2016)	Mobile technologies in the service of students' learning of mathematics: the example of game application ALEX in the context of a primary school in Cyprus.	15 – over 6	Pre test only	A.L.E.X.	Geometry	questionnaire
Miller, T. (2018)	Developing numeracy skills using interactive technology in a play-based learning environment.	13 – up to 6	Pre & post test	Intro to Math/Count-up-to-ten/ Preschool All-in-one/ Pre-school & Kindergarten Splash Math/ Preschool & Kindergarten Learning Games Basic Skills/ Addition/ Kindergarten Math Game/ Candy Count/ Junior Math/ Math School/ Coloring Book/Lola's Math.	Number & operations/ Algebra	Explain Everything app
Amorim, A. N. et al. (2023)	Exploring the Use of Escribo Play Mobile Learning Games to Foster Early Mathematics for Low-Income First-Grade Children.	726 – over 6	Pre & post test	Escribo Play	Number & operations/ algebra/ geometry	GEMMA assessment
Mera, C. et al. (2022)	Contributions of the psychology of mathematical cognition in early childhood education using apps.	193 – up to 6	Pre & post test	Compare amount -Quick counting-Calculation- Find the hidden number with Mon the dragon.	Number & operations	Test of Early Mathematics Ability–third edition (TEMA3)
Ökördi, R., & Molnár, G. (2022)	Computer-based intervention closes learning gap in Maths accumulated in remote learning.	810 – over 6	Pre & post test	eDia online platform	Number & operations	computer-based test
Lunardon, M. et al. (2023)	Math computerized games in the classroom: A number line training in primary school children.	183 – over 6	Pre & post test	The Number Line	Number & operations	Math achievement (AC-MT 6–11), *Number line (NL) task, Attention Network Test—ANT, Lexical decision task*

Appendix 2-1. Main Findings and Reported Academic and 21st-Century Skills of the Included Studies (N = 103)

Author/Year	Main Findings	Academic skills	21^{st} century skills
Rutherford, T. et al. (2014)	Results indicated a great improvement in experimental group's performance, yet not statistical significant.	Addition-subtraction, place value up to 1000, money, time and elapsed time, geometry and measurement,	None
Bui, P. et al. (2020)	The changes in game's interface benefited the student's performance and experiences.	Arithmetic operations	Attitudes
Brezovszky, B. et al. (2019)	As findings showed, the experimental group outperformed the control one on adaptive number knowledge and math fluency.	Arithmetic operations	None
Rodríguez-Aflecht, G. et al. (2017)	Regarding the 3 groups, the one that played in the school context completed more tasks, enjoyed the process more, yet didn't improve their mathematical skills as much.	Arithmetic operations	Motivation
Bakker, M., van den Heuvel-Panhuizen, M., & Robitzsch, A. (2015)	The experimental group who played the mini-games at home had a better performance than the control group.	Multiplication	None
Miller, D. J., & Robertson, D. P. (2011)	The experimental group had a greater improvement in accuracy and speed than the control group and also, there was statistically significant improvement in attitude towards school among the experimental group only.	Calculation	Attitudes
Ke, F. (2008)	Computer games did promoted significantly learning motivation but didn't improve math performance and metacognitive awareness. Also, the cooperative structure, compared to the competitive and individualistic ones, had a significant influence on attitudes towards math learning.	measurement problems, comparing whole numbers, solving simple equations, and mapping X and Y coordinates	Cooperation, competition, attitudes, motivation
Thai, K. P., Bang, H. J., & Li, L. (2021)	The experimental group who interacted with the digital game had much greater gains than the control group, specifically the more the kids played the more gains they had.	Number and operations in Base 10, algebraic thinking	None
Schacter, J., & Jo, B. (2017)	Students who interacted with the digital game had statistically significant improvement in their performance, especially the low achieving ones.	sorting, matching, and seriation activities, one to one counting, counting.	None
Gerholm, T. et al. (2019)	Results indicated that experimental and control groups didn't have statistical differences.	Early math, number sense.	None
Outhwaite, L et al. (2019)	Experimental groups interacted with the digital game had significant better improvement in their performance than the control group.	Number names, counting, patterns, shapes, space.	None
Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2018)	Both experimental groups had greater gains compared to the control one. In particular, the group that interacted with the tablets had significantly better results than the one with the computers.	one-to-one counting, cardinal counting, numeral identification, number composition and decomposition, subitizing, matching numerals to collections and addition and subtraction up to the number ten	None
Fraga-Varela, F., Vila-Couñago, E., & Rodríguez-Groba, A. (2021)	The results indicated that the digital game was beneficial for boys and girls equally.	mathematical fluency	None
Hassler Hallstedt, M., Klingberg, T., & Ghaderi, A. (2018)	The experimental groups did manage to score higher in mathematics compared to the control group only in basic math but not in problem solving or arithmetic transfer.	addition and subtraction up to 12 with a maximum of one double-digit number	None
O'Rourke, J., Main, S., & Hill, S. (2017)	Students who interacted with the digital game showed greater gains in learning and also motivation and self-efficiency.	Computation focus on speed and accuracy	Attitudes, motivation
Schacter, J., & Jo, B. (2016)	Results indicated that the experimental group had significantly improved their performance in mathematics, and more specifically they learned about one year more mathematics than the control group did.	quantities 1 to 3/1-6/1-9, subitizing, one-to-one counting, matching different quantity representations, cardinal principle, numeral identification, matching numerals to quantities, comparing quantities, and sequencing numerals and quantities, understand successive numbers, order numerals and quantities from least to greatest, place value.	None
Beserra, V., Nussbaum, M., Zeni, R., Rodriguez, W., & Wurman, G. (2014)	The two experimental groups – game-based & non-game-based- had significantly better results compared to the control group, however there wasn't a difference in their between comparison regarding learning gains. Also, their interest by using a means of technology was higher compared to the traditional method group.	Addition, subtraction, multiplication, division	None
Foster, M. E. et al. (2018)	The experimental group showed higher learning gains regarding Spanish mathematics but not for the English ones.	counting, comparing and ordering numbers, subitizing, composing numbers, adding and subtracting, multiplying and dividing, classifying, measuring, recognizing shapes, composing shapes, comparing shapes, spatial sense and motions, and patterning.	None
Gómez, F. et al. (2013)	The group that interacted with the digital games had achieved greater gains in aspects of oral language, logical-mathematical and social skills.	Matching, sorting	Collaboration
Volk, M., Cotič, M., Zajc, M., & Starcic, A. I. (2017)	The experimental group that interacted with tablets had greater improvement in their performance regarding conceptual knowledge, procedural knowledge and problem-solving skills.	Time, orientation using a map	None

Appendix 2-2. Main Findings and Reported Academic and 21st-Century Skills of the Included Studies (N = 103)

Papadakis, S., Kalogiannakis, M., & Zaranis, N. (2016)	The group that interacted with the tablets had enhanced significantly more in mathematics than the group who interacted with the computers.	numbering skills, numeral literacy, mastery of number facts, calculation skills and understanding of concepts.	None
Kolovou, A., van den Heuvel-Panhuizen, M., & Köller, O. (2013)	Regarding the post tests, experimental group showed an significant improvement in mathematical ability compared to pre tests.	covarying quantities	None
Fokides, E. (2018)	The experimental group, in most of the cases had a greater improvement in their performance than the other groups, and also their views for the games were highly enhanced.	Counting, decimal, fractions	Attitudes
Silander, M. et al. (2016)	Results indicated that the experimental group had greater performance than the control one, in aspects of ordinal numbers, spatial relationships and 3D shapes.	patterns, geometry (2-D and 3-D shapes, spatial relationships), measurable attributes, ordinal numbers, counting.	Attitudes (parents/care-givers)
Moyer-Packenham, P. S. et al. (2019)	Learning gains observed in digital games intervention, and there were also noticed some design features that enhance learning outcomes. More specifically, games that did not include linked representations and opportunities for linked physical actions didn't lead to significant gains.	Shapes, number line, division, decimal, fraction, numeral representation, coordination,	None
Hulse, T. et al. (2019)	The gamified version of the app led to greater improvement in students' performance than the non-gamified one. Particularly the low-achieved students had even better gains when completing more problems in the game.	Decomposing numbers, operations to combine terms rearranging terms to apply the commutative and associative properties, and adding terms to both sides of an equation.	None
Aragón-Mendizábal, E. et al. (2017)	The experimental group outperformed the control one with significantly better scores in mathematics.	classification, comparison, simple arithmetic problems, distribution, size discrimination, seriation and number line	None
Ramani, G. B. et al. (2019)	The digital game proved to enhance mathematical abilities of children, which remained when they were assessed one month later. However, those who participated in the working memory group didn't show similar results in maths, but playing both the math game and working memory game enhanced children's working memory.	numerical knowledge, working memory	None
Beşaltı, M., & Ümit, K. U. L. (2021)	Students in the digital game group showed a significant improvement in their performance and self-efficacy regarding fractions than students in the non-game group.	Fractions	None
Outhwaite, L. A., Gulliford, A., & Pitchford, N. J. (2017)	Results indicated that children who interacted with the digital game improved their math performance especially the low-achievers, an improvement that remained in the re-assessment after months.	Patterns and Shape, counting 1 to10, and Add and Take Away	None
Kim, H., & Ke, F. (2017)	The VR environment related to game-based learning (GBL) caused significant gains in mathematics compared to the non-GBL one.	Fractions	None
Ke, F., Grabowski, B. (2007)	Digital game enhanced students' math performance more in comparison to the drills, and also the cooperative structure led to better attitudes towards math.	measurement, comparing whole numbers, solving simple equations and mapping x and y coordinates	Cooperation, competition, attitudes.
McManis, M. H., & McManis, L. D. (2016)	Children who interacted with the digital game had greater learning gains regarding math and literacy, and specifically those who spent more time playing had the best improvement in their performance .	Shapes, sorting, patterning, counting, addition-subtraction, sequence, numerical recognition	None
Riconscente, M. M. (2013)	Results indicated that the experimental group who played with the digital game outperformed the control group with significant gains in math's performance, self-efficacy and attitudes towards fractions.	fractions, proportions, and percentages to the number line	Attitudes
Lee, H. K., & Choi, A. (2020)	The experimental group had greater learning gains in general compared to the control group, and particularly some of math's tasks were enhanced significantly after the intervention.	recognizing numbers, number operations, recognizing numbers and relationships, fraction recognition, recognizing measurements, recognizing shapes, gathering data.	None
Zaranis, N., & Valla, V. (2019)	Results indicated that the digital game led to a positive improvement in students' numeracy skills.	General mathematical thinking • Comparison • Classification • One-to-one correspondence • Counting	None
Weiss, I., Kramarski, B., & Talis, S. (2006)	Both experimental conditions – the individual and the cooperative – had significantly greater scores than the control group in math tests. Regarding their between comparison, the individual structure benefited children's knowledge acquisition while the cooperative one formed more positive attitudes towards cooperative learning.	number recognition, counting, grouping, comparing, estimating, addition-subtraction	Cooperation, Attitudes
Wang, S. Y. et al. (2018)	The experimental group performed better in mathematics course than the control one, and their motivation was enhanced as well as their attitudes towards the game.	Speed	Motivation, attitudes
Park, J. et al. (2016)	The preschoolers who interacted with the digital game showed some improvement in mathematics' skills that were investigated in comparison to the control group who interacted with a memory game.	Addition-subtraction	None
van der Ven, F. et al. (2017)	Results indicated a significant improvement of the experimental group on dot-subtraction efficiency compared to the control group.	Addition-subtraction	None
Lakshmi, D., & Ponnusamy, R. (2021)	The experimental group showed a significant increase in their mathematical skills and also their working memory.	Working memory	None

Appendix 2-3. Main Findings and Reported Academic and 21st-Century Skills of the Included Studies (N = 103)

Schenke, K. et al. (2020)	Children in the treatment groups performed significantly greater in post test, however no differences were found between them.	Height, length, weight, capacity	None
Jay, T. et al. (2019)	The experimental group who interacted with the digital game performed better than the control group, with an improvement in math equal to 7 months' progress.	Multiplication	None
Sýkora, T., Stárková, T., & Brom, C. (2021)	Results indicated that children did interacted with the game a lot, whether it included cutscenes or not, although there wasn't any between groups difference in math performance, attitudes or motivation.	Arithmetic skills, equal division, weight	Attitudes Motivation
Shin, N. et al. (2012)	The interaction with the digital game led to learning gains for children regarding arithmetic skills in all ability levels.	Addition- subtraction	Attitudes
Soydan, S. (2015)	Results indicated that the experimental groups who interacted with the smart boards and educational toys enhanced their performance in operational skills compared to the control group. Their between difference was observed only regarding subtraction skills in favor of the educational toys group.	Addition-subtraction	None
Peralbo-Uzquiano, M. et al. (2020)	The experimental groups – the digital and the paper & pencil one- had greater learning gains compared to the control group, however there wasn't any significant difference between them, except from their reaction speed which was in favor of the digital game group.	Basic mathematical skills	None
Szkudlarek, E., & Brannon, E. M. (2018)	Results showed that low-achievers performed significantly greater on informal symbolic mathematics compared to the control group, although it wasn't found a significant improvement for all children as it was hypothesized at first. In general, children with different pre-test scores benefited in different math abilities.	Addition Comparison, Subtraction Comparison, Matching Addition, and Matching Subtraction	None
McCarthy, E., Tiu, M., & Li, L. (2018)	Results indicated that that students' performance in mathematics was significantly improved and their motivation was also enhanced after interacted with the digital game.	Counting, identification of numbers, comparing, addition-subtraction	Motivation
Chen, Y. H. et al. (2012)	The experimental groups outperformed the control group, especially the low-achievers. Moreover, children in the collaborative structure performed better than children in the individual one.	Addition-subtraction	Collaboration
Beserra, V., Nussbaum, M., & Grass, A. (2017)	Children in the experimental group that interacted with the digital game using fine-grained multiple choice performed greater than the drill & practice one.	Addition-subtraction-multiplication-division	Attitudes
Freina, L., Bottino, R., & Ferlino, L. (2018)	The experimental group had significant greater learning gains in all aspects explored, compared to the control group.	Memory, movement and rotation of 2D/3D objects, spatial perspective	Attitudes
Vanbecelaere, S. et al. (2021)	Results indicated that the experimental group in the adaptive version had greater learning gains compared to the nonadaptive one.	number comparison, number line estimation, pictorial calculating, simple arithmetic	Math Anxiety
Rocha, M., & Dondio, P. (2021)	Children who interacted with the digital game performed significantly better compared to control group and showed great engagement.	Counting and numeration, patterns, operations, length, weight, spatial awareness, sorting/classifying objects	Attitudes, Math anxiety
Gecu-Parmaksiz, Z., & Delialioglu, O. (2019)	The experimental group gad greater learning gains when comparing the tests' scores, although in between groups comparison significant differences were observed only regarding the shapes of triangle, rectangle and square.	Shapes	None
Lin, Y. H., & Hou, H. T. (2016)	Results showed an improvement in children's route planning for those who interacted with digital games, which also benefited their views toward the game.	map reading, route mapping	Attitudes, motivation
Miller, D. J., & Robertson, D. P. (2010)	The experimental group performed significantly greater after interacting with the game in case of accuracy and speed of calculation.	Calculations, memorization	None
Es-Sajjade, A., & Paas, F. (2020)	Significant improvement was observed in math performance, but not in motivation, of children who interacted with the digital game compared to the children who didn't.	Equations	Motivation
McCarthy, E., Tiu, M., & Li, L. (2018)	Results indicated that students who interacted with the digital game performed significantly better and also aspects like motivation and engagement amongst others were enhanced.	Counting, comparing, number line, composing/decomposing numbers, addition-subtraction, cardinality, identifying digits/ the number after.	Cooperation, motivation
Hung, C. M., Huang, I., & Hwang, G. J. (2014)	All aspects that were investigated, except from math anxiety, were enhanced in favor of the experimental group after interacted with the game, including mathematics' performance, self-efficacy and learning motivation.	Symmetry	Attitudes, Math anxiety, Motivation
Akman, E., & Çakır, R. (2020)	Children who interacted with the digital game showed a high level of engagement and an improvement of their math' performance.	fractions	None
Kermani, H. (2017)	Results indicated that children's math performance was enhanced after interacted with the computer games in number sense, with the teacher's scaffolding having a great effect in it.	counting, numeral recognition and naming, identification of various properties of numbers, quantity discrimination, measuring, and estimation and prediction.	Cooperation
Lin, C. H. et al (2011)	The experimental group interacted with the digital game had significant greater learning gains compared to video-based group, however both groups improved their math performance.	area of a circle	None

Appendix 2-4. Main Findings and Reported Academic and 21st-Century Skills of the Included Studies (N = 103)

Räsänen, P. et al. (2009)	Results indicated that the domain of number comparison was the only one that led to better achievement for the experimental group in comparison to the group of normal-achievers.	comparison, counting (verbal and object), and arithmetic	None
Alzubi, T. et al. (2018)	The digital games interaction led to greater learning gains for children in mathematics and also their working memory, compared to a control group.	Working memory, calculating, counting, ascending/descending order for numbers.	None
Sung, Y.-T., Chang, K.-E., & Lee, M.-D. (2008)	Children who interacted with the digital game enhanced their performance in hierarchical taxonomic concepts.	Sorting, classification, matching.	None
Aladé, F. et al. (2015)	Both experimental groups, those who interacted with the digital game and those in the non-interactive videos performed greater than the control group. Their between difference was found in near-far transfer of knowledge, in which game-group performed better in near transfer tasks and the opposite happen to the video-group.	Length, height	None
Pope, H., & Mangram, C. (2015)	Significant learning gains were observed in the case of children who interacted with the digital game, compared to the control group.	Number line	None
Main, S., & O'Rourke, J. (2011)	The experimental group outperformed significantly the control group in speed and accuracy of calculations and self-efficacy .	mental calculation	None
Yang, K. H., Chu, H. C., & Chiang, L. Y. (2018)	Children who interacted with the digital game showed a significant improvement in their mathematics performance.	Addition-subtraction	None
Huang, Y. M., Huang, S. H., & Wu, T. T. (2014)	Results indicated that the digital game enhanced students' learning achievement and reduce their math anxiety levels as well.	Addition-subtraction	Math Anxiety, Motivation
Wang, F. et al (2016)	Children' s performance was enhanced after interacted with the digital game, regarding the post test scores, and also it was proved that they can transfer what they learned from the game to a real context.	Time	None
Wilson, A. J. et al. (2009)	The experimental group that interacted with the math digital game had greater learning gains in number sense pointing its strong effectiveness, especially in low-achievers.	numerical comparison, number and space, non-symbolic and symbolic representations of number, addition-subtraction.	None
Castellar, E. N. et al. (2015)	Results indicated that children's performance was improved in parallel with their working memory and their level of enjoyment.	mental calculation	Attitudes
Mohd Syah, N. E. et al. (2016)	The experimental group outperformed the control one with significant gains and also decreased two dyscalculia characteristics, number disorientation and confusion in operations.	Addition-subtraction	None
Kim, N., Jang, S., & Cho, S. (2018)	Results indicated that a significant enhancement was observed only in some of the math abilities that were examined.	non-symbolic numerosity comparison, non-symbolic numerosity estimation, approximate arithmetic, and symbol-to-numerosity mapping	None
Sella, F. et al. (2016)	The interaction with the digital game led to great learning gains regarding mental calculation and spatial mapping of numbers.	comparison of non-symbolic numerical quantities, mental counting	None
Schroeder, E. L., & Kirkorian, H. L. (2016)	As regards the math game, children who watched the game had greater learning gains than those who actually played it, however they didn't manage to transfer the information they got in any of the two conditions.	quantity, set size	None
Pareto, L. et al. (2012)	Results indicated that children who interacted with the digital game had significant better math performance compared to the control group, however regarding the attitudes there was no difference between the experimental and the control group.	place-value. Addition-subtraction-multiplication-division (carrying and borrowing), estimating sets	Attitudes, cooperation, competition
Bullock, E. P. et al. (2017)	Results demonstrated that the affordances of the apps as well as the children's age are crucial in the improvement of their performance. In particular, the actions of those who actually progressed where unique in contrast to those who regressed that had similar behavioral patterns.	Seriation, counting	None
Yang, J. C., & Chen, S. Y. (2010)	The experimental group who interacted with the pentominoes game had significant improvement in spatial abilities .	spatial abilities	None
Tucker, S. I. et al. (2017)	Analysis of the results showed that children did improve their math performance in several concepts based on their pre & post assessments.	subitizing, part-whole relations, counting, quantity in base ten	None
Käser, T. et al. (2013)	The experimental group improved significantly their math performance and also enjoyed their interaction with the digital game.	Cardinality, cordinality, relativity, arithmetic operations, word problems	Attitudes
Baccaglini-Frank, A., & Maracci, M. (2015)	Results indicated that children found challenging the one digital game although in the second one few were those who made no mistakes at all, and also different strategies were observed by children during their interaction with the digital games.	Subitizing, Recognizing parts of a whole, One-to-one correspondence Approximate estimation, counting	None
Mattoon, C. et al. (2015)	Both approaches – the digital and the traditional manipulatives- had great learning gains, however there wasn't found any significant difference between them.	Addition (mental), "missing addend" problem, equal division, counting	None
Fischer, U. et al. (2011)	Results demonstrated that the interaction with the dance mat led to an improvement in children's mathematical skills, specifically in spatial-numerical representation and therefore in counting.	magnitude comparison	None
Çakıroğlu, Ü. & Taşkın, N. (2016)	The experimental group showed greater improvement in math concepts in comparison to the control group, although they weren't statistically significant.	Matching, Grouping, Sorting, Concept of Number	None

Appendix 2-5. Main Findings and Reported Academic and 21st-Century Skills of the Included Studies (N = 103)

Hwa, S. P. (2018)	Results indicated that the experimental group had greater learning gains than the control group regarding mathematics performance.	Quantity Comparison, number (0-20), Numerals and Words, Ordinal Number, Addition- subtraction, Solving Daily Problems, Shape and Space, Time, Naming Days and Months	none
Baccaglini-Frank, A., Carotenuto, G., & Sinclair, N. (2020)	Children that interacted with the digital game improved their number sense abilities partly, some of them had greater achievement and some others struggled more. Analysis of the results focus on two specific children in detail, who did improved their math abilities.	Subitising, Finger gnosis and control, Representing numbers with Fingers, Ordinality, cardinality	None
Tucker, S. I., & Johnson, T. N. (2020)	Detailed analysis of child's interaction with the digital game indicated an improvement in her math performance, based on her increased accuracy in responding to quantities.	Subitizing	None
Zhang, M. et al. (2015)	The interaction with the digital game enhanced children's performance and also made the gap, between the low-achievers and the normal ones, smaller.	Multiplication, decimals	None
Broda, M. et al. (2019)	Results indicated that after the interaction with the digital game students responded faster and more accurate. A difference was observed between genders in favor of girls being more accurate than boys, and also between younger and older students in favor of the younger who were both faster and more accurate.	Subitizing, finger gnosis	None
Salminen, J. et al. (2015)	Children who participated in the study and interacted with the digital game significantly improved their math abilities of verbal & dot counting as well as basic arithmetic.	verbal counting, object counting, basic arithmetic	None
Ke, F. (2008)	Although there was not a significant improvement in children's math performance, their attitudes towards mathematics were enhanced after the interaction with the digital game.	measurement, comparing whole numbers, solving simple equations, and mapping X and Y coordinates	Attitudes, communication
Kyriakides, A. O., Meletiou-Mavrotheris, M., & Prodromou, T. (2016)	Results demonstrated that children who interacted with the tablet digital game improved their math performance in many aspects like symmetry etc., and also their attitudes towards mathematics.	motion, direction	None
Miller, T. (2018)	Results indicated that an improvement was noticed in favor of the intervention group although it wasn't statistically significant and cooperation amongst children was also observed.	Sorting, subitizing, Number recognition, counting, patterns, addition-subtraction, patterns, comparing quantities.	Cooperation
Amorim, A. N. et al. (2023)	The experimental group managed to achieve greater learning gains in math abilities of number identification, count-sequence, shapes and spatial sense in comparison to the control group.	number identification, count-sequence, set comparison, spatial sense, and geometric shape recognition.	None
Mera, C. et al. (2022)	Results indicated that the experimental groups who interacted with the digital games successfully improved their performance in the math abilities that were explored, compared to the control group.	magnitude, subitizing, number fact, estimation	None
Ökördi, R., & Molnár, G. (2022)	Both grades achieved significantly in their math performance, a fact that increases the potential of reduction of the learning gap that was created during the Covid in mathematics.	mathematical reasoning tasks, multiplication -division	None
Lunardon, M. et al. (2023)	Results indicated that improvement was noticed only as regards the accuracy in placing numbers on the number line.	Number line	None