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Digital game-based learning in mathematics education at primary school level: A systematic literature review

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Abstract

In recent decades, digital game-based learning (DGBL) has become a trend among scholars and practitioners in many parts of the world. Therefore, there were some systematic literature reviews in the past few years conducted to identify the trends of DGBL research with diverse subjects and educational levels, however, there is a lack of review that focuses only on mathematics education at primary school levels. This study seeks to provide a comprehensive overview of DGBL research within the context of elementary mathematics learning. Using PRISMA (2020) flow diagram, this study identified 45 articles related to the topic during the period of 2006-2023. Papers were coded and analyzed by years, regions, elementary mathematics topics, research issues, outcomes, research approaches, research design, data collection tools, game genres, and gameplay mode. The results from this systematic review identified the trends in DGBL research related to elementary mathematics learning, highlighted gaps in existing literature, provided insights, and oriented future studies on the topic. The findings of the research reveal a pronounced interest among scholars in the content topics of elementary mathematics, highlighting the research issues that attract attention, the methodologies employed in studies, and the types of games and gaming modes frequently utilized for elementary school children. The article discusses the trends of DGBL within elementary mathematics education, offering in-depth analyses and identifying research gaps that could guide future directions.

Keywords: elementary students, game-based learning, learning games, math learning

INTRODUCTION

The rapid development of technology has been changing every aspect of human living, significantly shaping the way how we teach and how we learn. Raising from the growth of educational technology in recent decades, digital game-based learning (DGBL) has become a trend among scholars and practitioners in many parts of the world. A lot of empirical studies have pointed out that DGBL can have positive impacts on many aspects of students' learning, such as knowledge acquisition, perceptual and cognitive skills, affective and motivational outcomes, and behavior change outcomes (Connolly et al., 2012; Hainey et al., 2016; Hussein et al., 2022). In addition, DGBL is usually mentioned as a motivating, attractive, and engaging approach thanks to well-designed game elements like virtual characters, challenges, quests, rewards, avatars, etc. (Abdul Jabbar & Felicia, 2015). Therefore, Hussein et al. (2022) described DGBL as "a student-centered approach, where educational objectives and material are embedded in gaming activities in an attempt to motivate students to learn and improve their skills and knowledge by providing them with an enjoyable and interactive learning environment". Although the definition of DGBL may differ among scholars, most researchers agree that it provides a motivational learning environment (Clark et al., 2016; Hussein et al., 2022) to enhance student learning via using advantage of digital games (Byun & Joung, 2018; Qian & Clark, 2016; Tang et al., 2009; Van Eck, 2015).

Several studies in the field of DGBL have been conducted at every learning level, with participants ranging from preschoolers (Crescenzi-Lanna, 2022; Fang et al., 2022), elementary students (Kamalodeen et al., 2021; Pareto, 2010) to adults (Chang & Hwang, 2019).

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Contribution to the literature

- A systematic review of DGBL in mathematics education at primary school level is conducted in this study.
- The chosen studies were systematically analyzed by years, regions, elementary mathematics topics, research issues, outcomes, research approaches, research design, data collection tools, game genres, and gameplay mode to provide a current synthesis for the scholarly community.
- For the advancement of DGBL in elementary mathematics learning, this review provides new insight information.

Digital games have been used in teaching various subjects: language, science, social science, natural science, mathematics, or soft skills and social skills (i.e., collaboration skills) (Andersen & Rustad, 2022). Regarding DGBL in mathematics education, the number of research articles has been increasing recently, especially since 2014 till now (Chen et al., 2022). In the context of the proliferation of studies, there is a need to conduct systematic literature reviews to summarize the trends in DGBL research on mathematics education, providing the current trends of the research topic, and thereby help to guide new studies, shed light on using DGBL appropriately in teaching and learning. The previous reviews related to the topic are summarized in **Table 1**.

As shown in **Table 1**, the previous review focused on identifying the trends in K-12 education in general or summarized DGBL used in various subjects like science, languages, etc. There is still a need to look more deeply into DGBL research on mathematics education since mathematics is considered one of the most critical subjects in the curriculum. Researchers suggested that DGBL enhances students' cognitive skills like reasoning, modeling, or problem-solving skills (Araya et al., 2014; Bottino et al., 2007; Sun et al., 2011), which are essential skills in mathematics learning.

Although some reviews focused on DGBL in K-12 mathematics education (see **Table 1**), there still needs to be more reviews focusing on primary education. This learning stage has many specific characteristics compared to other learning levels. It has been claimed in several studies that elementary students learn mathematics differently from secondary or high school students. Playing has a crucial role in their positive development and learning (Josh et al., 2017; Parker & Thomsen, 2019), giving DGBL chances to be a promising learning approach for this learning stage.

While previous reviews have explored various aspects of mathematics education, they have often encompassed a broad range of educational levels, from elementary to higher education, without a specific focus on primary education. Mathematics education at the primary level is distinguished by unique content topics and core competencies that are fundamentally different from those at higher educational levels. In primary education, the focus is on foundational math concepts and basic skills development. Besides, the way in which digital games are utilized for mathematics education varies between elementary-aged children and older students. So, a targeted systematic review of DGBL that focuses solely on primary mathematics education is necessary to specifically address the unique challenges and opportunities present at this crucial stage of educational development.

In the context of DGBL used in mathematics education for elementary students recently, it is necessary to identify the trends in research topics, methodologies, and evaluative measures. Additionally, it is essential to identify commonly and less commonly addressed mathematics topics, as well as to determine the game genres that are predominantly utilized for elementary students. In other words, it is necessary to provide the current state-of-the-art potential of DGBL at the primary education level to orient future studies. The main focus of our study was to synthesize the articles involving DGBL in mathematics education at the primary education level published from January 2006 to May 2023. To guide our research, we proposed three research questions (RQ) below:

RQ1. What was their distribution by years, regions, and elementary mathematics topic?

RQ2. What were the most research interests in DGBL for elementary mathematics education? In particular, what were the dominant research issues and learning outcomes investigated in those studies?

RQ3. What were the most commonly used research approaches, research designs, and data collection tools?

RQ4. What were the trends in game genres and gameplay modes (e.g., individual play, collaborative play, and competitive play)?

In the following parts, we present methods to conduct the systematic literature review and results from data extraction and discuss the findings by answering those three questions.

METHODS

Search Strategy

Three data databases, including ProQuest, Science Direct, and Springer Link, were used to gather relevant journal articles.

Table 1. Some recent highly cited literature reviews on DGBL

Reference	n	Period	Research object	Interest of review
Chen et al. (2022)	146	1991-2020	DGBL in science & mathematics education	Most influential authors/regions, platforms/game genres used, subjects (mathematics, physics, biology, chemistry, etc.), research methods & measurement, & keywords
Hafiza Razami and Ibrahim (2022)	33	2009-2022	Models & constructs to predict students' digital educational games acceptance	Digital educational games acceptance among students: predictors, model, & variables
Hussein et al. (2022)	43	2008-2019	DGBL effectiveness in K-12 mathematics education	Evidence-based discussion concerning effectiveness of DGBL in K-12 mathematics & detailed insights into current trends in K-12 mathematics education
Pan et al. (2022)	43	2009-2021	Games used for math learning & game design elements	Research methodologies, how games were used in studies, how learning was integrated into game world & game mechanics
Gao et al. (2020)	30	2010-2019	Mobile game-based learning in STEM education	Research foci, methodologies & measurement, factors that affect nature of mobile game-based learning, & learning theories or principles guide design of games
Chang and Hwang (2019)	113	2007-2016	DGBL in mobile era	Game types, devices, learning strategies adopted in mobile DGBL, research methods, & participants
Boyle et al. (2016)	143	2009-2014	Empirical evidence of impacts & outcomes of computer games	Research design, game types/genres, & learning outcomes
Clark et al. (2016)	69	2000-2012	Digital games: Design & learning for K-16 students	Comparisons effect of a game vs. nongame conditions & comparisons effect of augmented games vs. standard game designs
Hainey et al. (2016)	105	2000-2013	DGBL empirical evidence in primary education	Research design, methods, & analysis, & generalization of findings
Qian and Clark (2016)	137	2010-2014	DGBL & 21st century skills	Learning outcomes related to 21st century skills, game genres, & game elements, & learning theories
Abdul Jabbar and Felicia (2015)	91	2003-2013	Game design features that promote engagement & learning in DGBL	Game design features (type, genre, world, event, engagement elements, etc.), learning outcomes, & research methods
Connolly et al. (2012)	129	2004-2009	Empirical evidence of computer games (users aged 14 years or above)	Game perspectives (digital or non-digital, genres, & platform), effects of games, & research perspectives (design, sampling, measurements, & results)

Prior research (Hussein et al., 2022; Pan et al., 2022) examining DGBL within context of K-12 mathematics education employed a lexical strategy incorporating a fusion of terminologies associated with DGBL (for instance, game-based learning or serious game) and those pertinent to mathematics education (such as math learning or teaching math). In the current investigation, we included an additional set of search terms specifically aligned with primary education. The keywords used were combination of three following sets of terms, with Boolean "OR" used to join terms in each set and Boolean "AND" was used to combine the following three sets:

(1) Game*, Gaming, "digital game*", "video game*", "serious game*", "Game-based learning", "Digital game-based learning",

(2) Math*, "Math* education", "teaching math*", "learning math", arithmetic, calculus, numeracy, geometry, and

(3) Elementary, primary.

To select the appropriate articles, we applied PRISMA 2020 flow diagram, including three stages of the extraction process: identification, screening, and including, which is shown in **Figure 1**.

The included criteria are, as follows:

(1) the study is an empirical study,

(2) the study is related to DGBL,

(3) the learning objectives are related to mathematics,

(4) the participants are elementary students, and

(5) the date of publication was between January 2006 to June 2023.

Articles that were removed from the review because of excluded criteria, including

(1) the game used was not digital,

(2) participants are particular, i.e., special needs kids or gifted students, and

(3) the study is a review.

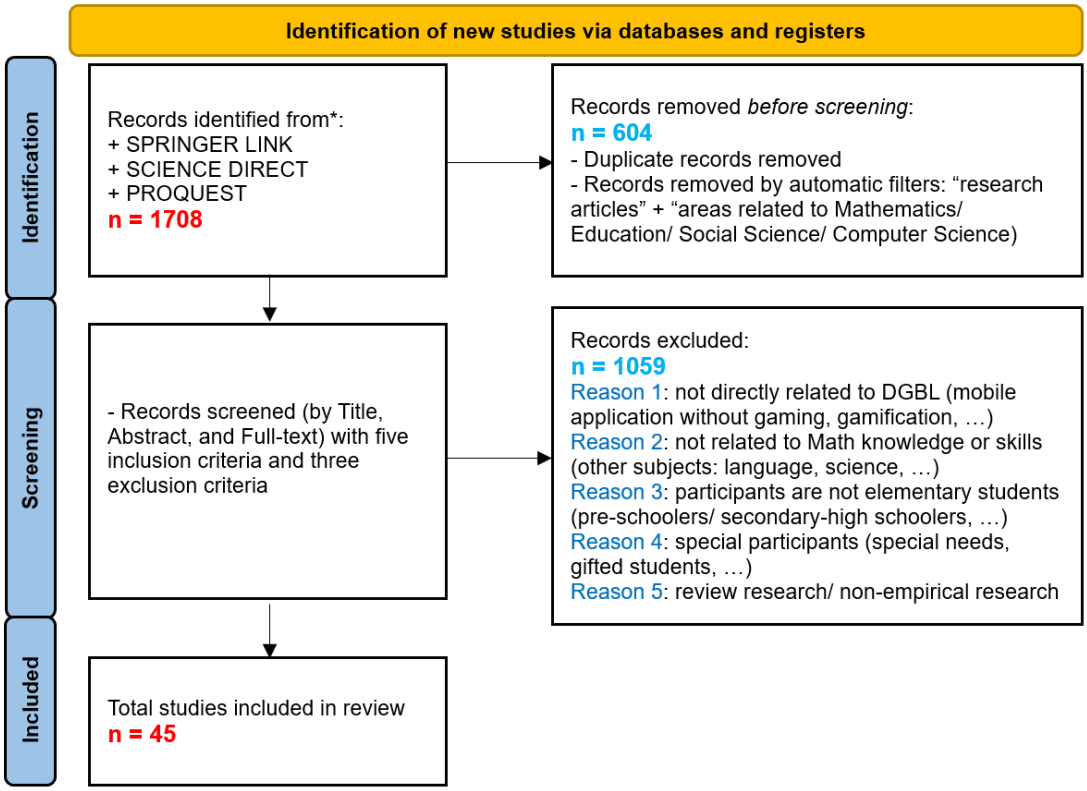

Figure 1. PRISMA 2020 flow diagram for this systematic review study (Source: Authors' own elaboration)

Finally, only 45 articles (**Appendix A**) that met all inclusion and exclusion criteria were selected for review. Scopus quartile ranking of chosen articles are Q1 (n=36), Q2 (n=7), and Q3 (n=2). **Appendix A** shows 45 articles used in this review.

Data Coding & Analysis Strategy

45 articles were analyzed according to following 10 factors:

(1) year of publication,

(2) region, where the study was conducted,

(3) elementary mathematics topics (e.g., arithmetic, geometry and measurement, statistic, and probability),

(4) research issues,

(5) learning outcomes,

(6) research approaches,

(7) research design,

(8) data collection tools,

(9) game genres, and

(10) gameplay mode (e.g., individual, collaborative, and competitive).

To any research topic, there are always several research issues, and so is DGBL. To code those issues, we adopted the categorization in Wu et al. (2012) systematic review of game-assisted learning research, which clarified the purposes of the reviewed studies that used games to enhance learning into four groups:

(1) evaluating the effectiveness of games,

(2) exploring learners' experiences,

(3) goals related to developing a learning tool, and

(4) developing new teaching methods.

In terms of DGBL effectiveness, All et al. (2015) suggested that an effective DGBL intervention should be able to enhance outcomes, including learning or motivational outcomes.

It is crucial to identify the trend in outcomes that DGBL studies focused on mathematics education at the primary education level. To code outcomes, we chose the categorization based on Connolly et al.'s (2012) review, which was also adopted in recent reviews (Hainey et al., 2016; Hussein et al., 2022). Categories are, as follows:

(a) knowledge acquisition/content understanding,

(b) perceptual and cognitive skills,

(c) affective and motivational outcomes, and

(d) behavior change.

Research approach and design were coded following Creswell and Guetterman (2019) categories, including three approaches (qualitative, quantitative, and mixed) and eight types of research design: experimental research, correlational research, survey research, grounded theory research, case study, narrative research, mixed method research, and action research. Regarding data collection tools, we adopted the categories suggested by Korkmaz and Morali (2022), comprising four tools: interview, questionnaire-test-scale, observation, and documents.

Table 2. Categories of digital educational games by Heintz and Law (2015)

Genres	Main properties	Examples
Mini-game	Single-player, restricted move, static goal, score as reward, abstract & pre-define setting, & fixed perspective	Candy Crush Saga
Action	Fight/move freely, opponents, time-pressure, & static goal	Temple Run
Adventure	Collect/move freely, puzzle/search/discover, explore/ fantasy setting, story, & game is finished (after all parts are done)	Tomb Raider
Role-play	Fight/move freely, communicate, collect, personalize, various goal (self-defined), power-ups as reward, explore/fantasy setting, endless/continuous story, & perspective is bound to character	Sim
Resource	Collect/move freely, limited resources, scores as rewards, & perspective is freely moveable	Minecraft
Other	Not one of the above	Card game

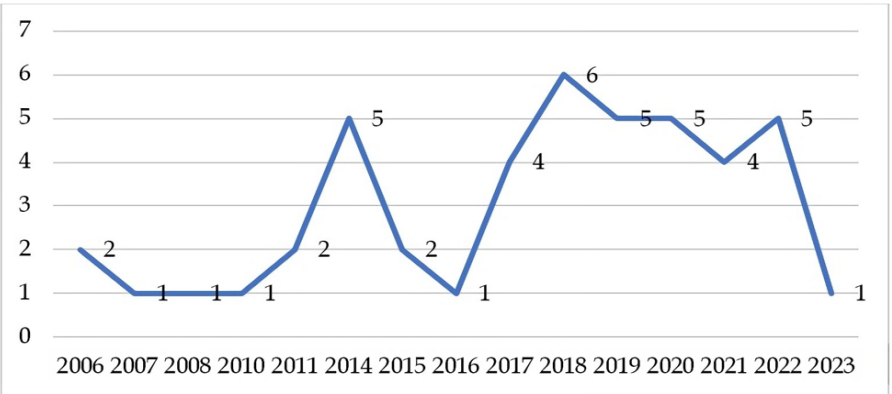

Figure 2. Distribution of papers by year (Source: Authors' own elaboration)

Figure 3. Distribution of papers by region (Source: Authors' own elaboration)

In addition, the game is the main character in DGBL research, so it is necessary to identify the trends in game genres, game types, and gameplay modes. Video game has been developed for decades and has been used for different purposes. Therefore, there are various categories of game types, depending on domains or their uses. For educational digital games, we adopted the game genres by Heintz and Law (2015), which clarified games as five main genres shown in **Table 2**. For some other games, like digital card games or gamification, we coded them as other types.

RESULTS

Distribution by Years & Regions

As shown in **Figure 2**, 45 articles were published between 2006 and 2023, with a few of the works early, then suddenly surging in 2014 and becoming a trend in the past few years (2017-2022). The three countries that have made the most contributions to this field are the USA (n=10), Taiwan (n=8), and Finland (n=4). **Figure 3** shows the geographical distribution of the 45 studies.

Table 3. Number of papers by topic

Topic	Number of articles (n)
Arithmetic	32
Geometry and measurement	10
Statistic and probability	0
Skill (problem-solving skill, reasoning skill, etc.)	8
Not mention	1

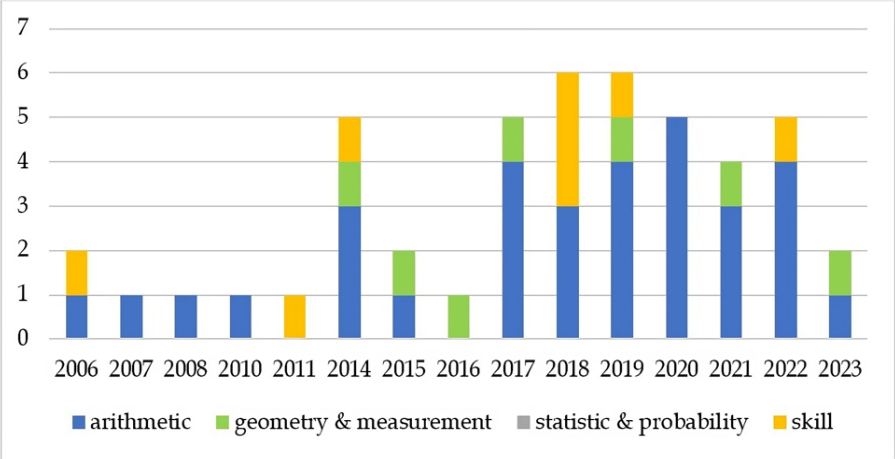

Figure 4. Distribution of papers by topics through years (Source: Authors' own elaboration)

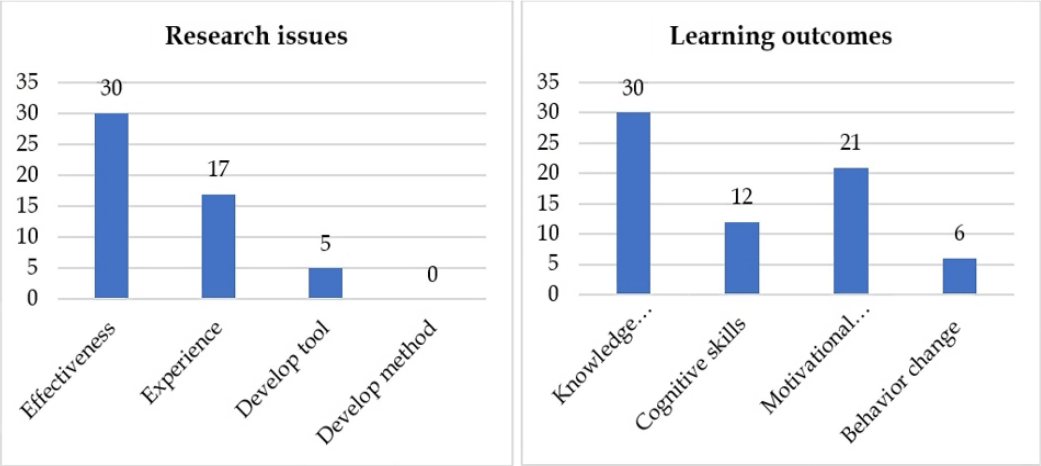

Figure 5. Distribution of research issues & learning outcomes (Source: Authors' own elaboration)

Elementary Mathematics Topic

In **Table 3**, arithmetic was dominant with 32 papers, including various sub-topics in elementary mathematics curricula like natural numbers, operations, fractions, decimals, etc.

This was also the topic that spread through the years since the beginning, as shown in **Figure 4**. The less common topic was geometry and measurement, which only appeared since 2014 when DGBL gained attraction.

Following those two topics, skills like problem-solving or reasoning, essential in competency-based learning, also got attention with eight works. No paper focusing on statistics and probability was found in the 45 articles.

Research Issues & Learning Outcomes

As shown in **Figure 5**, most studies aimed to evaluate DGBL effectiveness (n=30). Those studies examined if DGBL intervention positively impacted elementary students' mathematics learning by improving academic achievement, enhancing learning interest, or reducing math anxiety (Hung et al., 2014; Yeh et al., 2019). Besides, students' experience with games was the second most attractive topic with 17 studies. Few studies focused on developing new learning tools (n=5). For instance, Hou et al. (2022) compared the different effects among three game versions with different game elements to figure out which design is suitable for more insights into developing games as learning tools in the future.

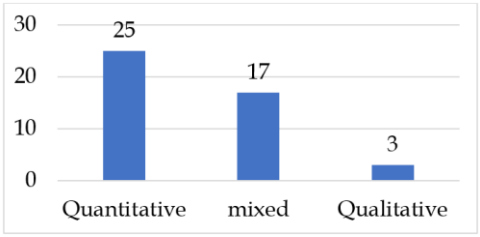

Figure 6. Distribution of publication by research approach (Source: Authors' own elaboration)

Finally, there needed to be more research that aimed to develop new teaching-learning methods in the field of DGBL in mathematics education for elementary students.

Regarding learning outcomes that got attention from researchers, knowledge acquisition/content understanding was the dominant theme in 30 studies. Affective and motivational factors got the second position (n=21), followed by cognitive skills (n=12). Behavior change (i.e., students' attention, class engagement, on-task and off-task during class, etc.) was the least expected outcome that appeared in five articles.

Research Approach & Design

Figure 6 shows distribution of publication by research approach. Of the 45 articles, the most commonly used was the quantitative approach with 25 papers, followed by the mixed approach (n=17).

Looking more deeply into the research designs, we found the dominant experimental and mixed method research, with 21 papers and 17 papers, respectively (see **Table 4**).

Qualitative research is only used by a few studies (n=3) to investigate more deeply in some case studies (n=3). There was one paper that adopted cluster analysis to determine clusters of players from nearly 10,000 players with a massively multiplayer online game, which was coded as "other design".

Figure 7 shows distribution of publications by research design through years.

Table 4. Number of papers by research design

Research design	Number of papers
Experiment research	21
Correlational research	1
Survey research	2
Case study	3
Mixed method research	17
Other (cluster analysis)	1

Table 5. Data collection tools in 45 articles

Collection tools	n	Examples
Questionnaire test scale	40	Learning achievement test Cognitive skill test Interest scale Motivation scale Attitude scale Math anxiety scale
Interview	12	Student interview form Teacher interview form
Observation	22	Video recording during students play Game data log Gameplay recording screen

Data Collection Tool

The most commonly used research approach mentioned above was the quantitative approach, which, of course, would affect the trend in using data collection tools corresponding to it. As shown in **Table 5**, the questionnaire-test-scale, one of the solid tools for quantitative research, was the most commonly used tool to gather data in the 45 articles (n=40). The observation was used quite frequently adopted in 22 studies. It should be noted that observation is about more than just watching directly or video-recording students while playing and studying. It also includes other specific tools to observe gameplay like screen-record, students' game logs saved on devices, etc. Finally, research that adopted a mixed or qualitative approach also used the interview to investigate more about learning or playing experience from the perspective of teachers and students.

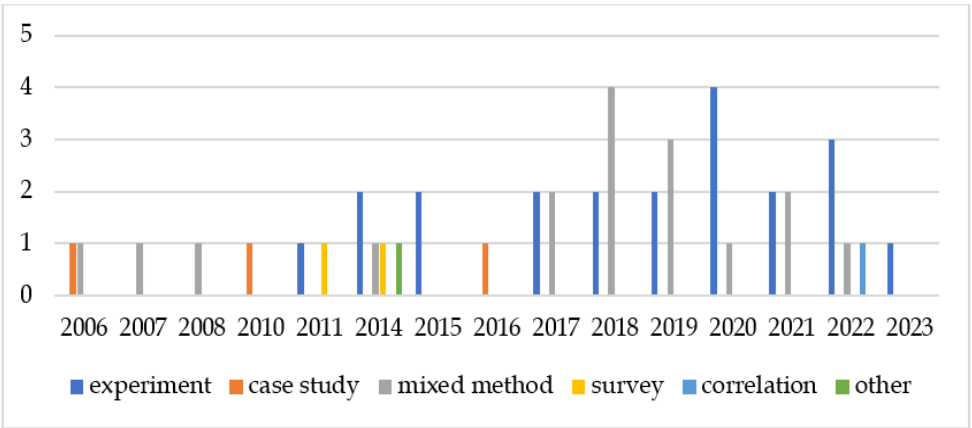

Figure 7. Distribution of publications by research design through years (Source: Authors' own elaboration)

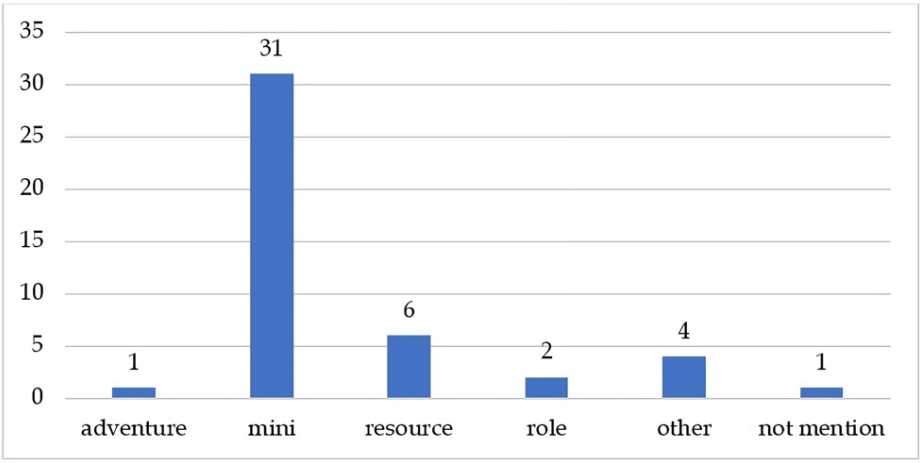

Figure 8. Number of games for genres (Source: Authors' own elaboration)

Table 6. Gameplay mode

Gameplay mode	Number of games
Individual	32
Collaborative	4
Competitive	4
Multi-mode	2
Not mention	3

Game Genres & Gameplay Mode

As shown in **Figure 8**, most papers used or designed mini-games in their studies, such as puzzle games or quizzes, which usually asked students to learn or practice knowledge and skills by answering riddles (questions). For instance, the game "Brick Breaker" in Hung et al. study (2014) has main gameplay mechanics that allow students to choose to break a brick; then, the learning system will immediately show a related question for them to answer and gain points if the answer is correct. The resource, role-playing, and adventure genres are less likely to be used in DGBL for teaching mathematics to elementary students.

In terms of gameplay mode, **Table 6** shows that individual mode (n=32) is more dominant than collaborative and competitive mode. Games are usually used as individual learning tools on students' devices (personal computers, tablets, smartphones, etc.).

DISCUSSION

Play serves as a crucial mechanism for learning, acting as a bridge for children to reach higher levels of cognitive and social development. According to Vygotsky (1978), through play, children engage in activities beyond their age and capabilities, thus promoting their zone of proximal development, where they can achieve tasks with the guidance and encouragement of others, enhancing their problem-solving skills and understanding of mathematical concepts (Bodrova et al., 2013; Langton, 2023). DGBL leverages the strength of gameplay activity to engage students, fostering better learning outcomes by promoting deep and motivating learning environments. Drawing on foundational educational theories, such as Piaget's stages of cognitive development and Vygotsky's (1978) social constructivism, it should be noted that children at elementary school ages exhibit distinct learning and playing styles compared to those at higher learning stages, due to their developmental emphasis on concrete operational thinking and the role of social interaction in constructing knowledge.

This review presents a valuable synthesis of studies on DGBL in mathematics education for the primary education level, allowing for a better knowledge of their distribution, approaches, and games used. In the below parts, we will discuss by answering the research questions proposed.

RQ1. What Was Their Distribution by Year, Region, & Elementary Mathematics Topic?

The distribution in results shows that the topic of DGBL in mathematics education for elementary students is still developing. Many studies appeared between 2014 and 2022, consistent with previous reviews by Chen et al. (2022) about DGBL in mathematics and science for K-12 students. Top-3 countries with the most contributions to the field are the USA, Taiwan, and Finland, according to Chang and Hwang's (2019) review.

In terms of math topics, Pan et al. (2020) have pointed out that articles in their reviews mostly choose arithmetic as the topic, followed by algebra and geometry. In this study, we focused on elementary mathematics topics and found the same trend as the previous review. The dominant topic included various topics, such as natural numbers (Lee & Choi, 2020), rational numbers (Kärki et al., 2022), fractions (Zhao et al., 2021), and operations (van der Ven et al., 2017). It can be seen that geometry and measurement are much less common and only appeared after 2014. This finding is consistent with a previous review by Byun and Joung (2018), which presented that arithmetic topics dominate more than other topics. In addition, we found a lack of

research that uses games for statistic and probability learning, although this topic is included in primary-level curricula of some countries.

Nowadays, competency-based curricula in many countries aim to develop cognitive and 21st century skills rather than absorb mathematics knowledge. Only eight of the 45 articles investigated the effect of DGBL in enhancing cognitive skills, like problem-solving skills (Sun et al., 2018, 2022), modeling skills (Araya et al., 2014), and reasoning skills (Pareto, 2014).

In addition, there needs to be more research in DGBL field that focuses on 21st century skills, including collaboration, creativity, and critical thinking, the gap pointed out in the previous review by Hussein et al. (2022).

RQ2. What Were Dominant Research Issues & Learning Outcomes Invested in Those Studies?

The results showed that evaluating games' effectiveness was the most common research interest in the 45 studies, while research on developing new tools or teaching methods needed to be more extensive. The order of popular research issues in this study was consistent with Wu et al.'s (2012) review. The effectiveness of DGBL on math learning has been claimed in many studies before and has even been synthesized in some meta-analyses (Karakoc et al., 2022; Wouters et al., 2013). Therefore, future research should not only seek evidence of DGBL impacts on math learning but also investigate more deeply, like why and how a specific game element or game characteristic enhances learning, from then develop better games or versions of games. In addition, it is crucial to determine how best to utilize digital games as a teaching or learning strategy. In other words, developing new learning tools and teaching methods in the field of DGBL should be focused more on the future for better math learning at the primary education level.

Regarding learning outcomes, the review of DGBL in K-12 mathematics education by Hussein et al. (2022) and the review of DGBL in various subjects at the primary education level by Hainey et al. (2016) found that knowledge acquisition or content understanding was the most popular one. The results in this study also found the same trend for DGBL in mathematics education in primary education. Besides, affective and motivational outcomes also received much attention. Video games were invented as a human recreational form, so their nature is associated with fun, motivation, and attraction. Therefore, it is easy to understand why researchers utilized games to enhance affective and motivational factors like reducing math anxiety (Hung et al., 2014), learning interest (Yeh et al., 2019), and math motivation (Hoffman et al., 2021). Connolly et al. (2012) pointed out that much empirical evidence has been found regarding learning and motivation outcomes. However, soft skills or social skills were lacking in DGBL research, and so did this study. In this review, we also found that a few studies (n=12) aim at cognitive skills like algorithmic thinking skills (Hsu & Wang, 2018), problem-solving skills (Sun et al., 2022), or represent skills (Moyer-Packenham et al., 2022), but only one paper focus on collaborative skill (Halloluwa et al., 2018), which is considered as soft skills. In recent years, many countries have been developing their curriculum based on competency orientation, which focuses more on 21st century skills, including soft skills and social skills. Findings in our study suggest that future research should consider those skills as essential outcomes. DGBL provides opportunities to enhance learning but also have positive impacts on developing 21st century skill (Qian & Clark, 2016).

RQ3. What Were the Most Commonly Used Research Approaches, Research Designs, & Data Collection Tools?

Consistent with the previous reviews by Chang and Hwang (2019) and Pan et al. (2022), experimental design with pre-test and post-test was the most commonly used in DGBL research recently with questionnaire-test-scale instruments. The approach can be quantitative or qualitative, depending on the authors' research purposes, so the collection tools were also varied. For more in-depth information, researchers used not only classroom observations (directly or via video records) but also game log data that can provide rich information like the number of completed tasks, total score, play speed, incorrect and correct answers by players … (Bang et al., 2023; Bui et al., 2020; Kärki et al., 2022; Lee & Choi, 2020). Those kinds of instruments can provide opportunities for qualitative research, which aims to investigate the phenomenon deeply. However, there were only three in 45 chosen articles adopted this approach. Therefore, future research in this field should take advantage of those digital tools to collect rich data to seek the answer not only to a simple question like "is DGBL an effective intervention or not?" but also to how and why DGBL affects students learning. For instance, based on users' game gestures collected from the screen recorder or students' reaction during tasks collected from the webcam, researchers can discover which game element get students' attention most or how a game's function helps students learn better. From then on, more complex research issues, as we mentioned in the previous part (**RQ2**), can be unveiled in the future.

RQ4. What Was Trend in Game Genres & Gameplay Mode (e.g., Individual Play, Collaborative Play, & Competitive Play)?

The previous review by Chang and Hwang (2019) found that role-playing, simulation, and gamification were the top three genres used by studies between 2007 and 2016. However, another review by Pan et al. (2022)

pointed out that the most common genre was puzzle games (i.e., quizzes). The difference may come from the way that games are categorized. For example, in a puzzle game, the main mechanic is "answering quizzes" that allow students to choose a fantasy avatar (i.e., a robot or an astronaut). It can be categorized as a "puzzle game" or "simulation game," depending on how we describe those genres. In this review, we chose Heintz and Law's (2015) categories, as mentioned above, and found that mini-games, which include puzzle game, was the most popular genres. This was consistent with previous studies that pointed out the trends in DGBL mostly used "practice and drill" format games with simple designs.

It should be noted that simple games that present materials in a quiz format or practice and drill do not always succeed in engaging students (Qian & Clark, 2016), and they may lose their game flow after a long time playing the games (Beserra et al., 2019). A case study by Fokides (2018) showed that poorly designed games may impact the effectiveness of DGBL intervention because those games cannot compete with the appeal of commercial off-the-shelf games. Design factors of a game, including storyline, characters, quest, and play mechanics, etc. are crucial and need more research to understand what kinds of designs support learning of particular content and how they support it. Future studies should focus more on complex and well-designed games that engage learners in reflective, high-thinking levels.

In terms of play mode, most games are only individually played. In the context of competency-based education, collaborative skill is one of the key objectives in the curriculum, so future research should focus more on collaborative and competitive modes, which provide students with the opportunity to play and learn together, help each other to complete challenging tasks or try to win others by trying harder. Vygotsky's (1978) theory of social constructivism underscores the paramount importance of collaborative learning among children, positing that through social interaction, children learn much more effectively, as they construct knowledge through shared experiences and dialogue, thereby illuminating the critical role of peer interaction in the cognitive development process. Pan et al. (2022) discussed that collaborative play mode may significantly improve mathematics knowledge gains or improve positive attitudes toward math learning. In addition, which gameplay mode among those three modes can help students better in knowledge acquisition or develop high cognitive skills and soft skills? That is an interesting question to be explored in the future.

Limitations

In this review, the findings reported here were limited by the search terms, journals from ProQuest, Science Direct, and Springer Link, and papers published between January 2006 and June 2023. Moreover, some articles may need to be included due to the search terms and methods. The second limitation concerns the publication type; we focused only on peer-reviewed journals, and the concluding remarks of proceedings, book chapters, or PhD dissertations were excluded.

CONCLUSIONS

This study aimed to describe the trend in DGBL in mathematics education at the primary education level. Most studies reviewed chose arithmetic as the learning topic. Future research should investigate further the topics of geometry, measurement, statistics, and probability. In addition, math skills, soft skills, and social skills should be investigated more. In terms of research issues, more research is needed in developing games as tools that support academic math learning or shaping new teaching methods. The strength of some kinds of data collection tools in DGBL fields, as discussed in this study, shows the potential to adapt effectively to answer those new complex research problems.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A

Table A1. 45 papers included in this review

ID	Paper's code name	DOI
1	Bang et al. (2023)	https://doi.org/10.1007/s10643-022-01332-3
2	Pan and Ke (2023)	https://doi.org/10.1007/s11423-022-10183-z
3	Hou et al. (2022)	https://doi.org/10.1007/s40593-021-00250-6
4	Kärki et al. (2022)	https://doi.org/10.1007/s10649-021-10120-6
5	Leonardou et al. (2022)	https://doi.org/10.1186/s40561-022-00195-w
6	Moyer-Packenham et al. (2022)	https://doi.org/10.1007/s10758-021-09506-5
7	Rebollo et al. (2022)	https://doi.org/10.1007/s11042-021-10821-3
8	Sun et al. (2022)	https://doi.org/10.1016/j.compedu.2022.104534
9	Hoffman et al. (2021)	https://doi.org/10.1007/s10758-020-09450-w
10	Vanbecelaere et al. (2021)	https://doi.org/10.1111/bjet.12957
11	Zhao et al. (2021)	https://doi.org/10.1007/s11423-021-10053-0
12	Bui et al. (2020)	https://doi.org/10.1007/s11423-020-09755-8
13	Bui et al. (2020)	https://doi.org/10.1007/s11423-020-09755-8
14	Celik (2020)	https://doi.org/10.1007/s10639-019-09983-3
15	Es-Sajjade and Paas (2020)	https://doi.org/10.1007/s11423-020-09799-w
16	Lee and Choi (2020)	https://doi.org/10.1007/s11423-020-09808-y
17	Hulse et al. (2019)	https://doi.org/10.1007/s11423-019-09653-8
18	Ke (2019)	https://doi.org/10.1007/s11423-018-09643-2
19	Moyer-Packenham et al (2019)	https://doi.org/10.1016/j.chb.2018.09.036
20	Ramos and Melo (2019)	https://doi.org/10.1007/s40692-018-0111-3
21	Yeh et al. (2019)	https://doi.org/10.1186/s41039-019-0100-9
22	Fokides (2018)	https://doi.org/10.1007/s10639-017-9639-5
23	Gresalfi et al. (2018)	https://doi.org/10.1007/s11423-017-9557-7
24	Halloluwa et al. (2018)	https://doi.org/10.1007/s00779-017-1073-6
25	Heshmati et al. (2018)	https://doi.org/10.1007/s10763-016-9789-8
26	Hsu and Wang (2018)	https://doi.org/10.1016/j.compedu.2018.02.002
27	Kiili et al. (2018)	https://doi.org/10.1016/j.compedu.2018.01.012
28	Sun et al. (2018)	https://doi.org/10.1016/j.compedu.2018.01.001
29	van der Ven et al. (2017)	https://doi.org/10.1016/j.chb.2017.02.031
30	Kyriakides et al. (2016)	https://doi.org/10.1007/s13394-015-0163-x
31	Lin and Chen (2016)	https://doi.org/10.1016/j.chb.2015.12.026
32	Valle-Lisboa et al. (2016)	https://doi.org/10.1007/s11125-017-9392-y
33	Núñez Castellar et al. (2015)	https://doi.org/10.1016/j.compedu.2014.12.021
34	Araya et al. (2014)	https://doi.org/10.1007/s11280-012-0173-5
35	Huang et al. (2014)	https://doi.org/10.1007/s11423-013-9315-4
36	Hung et al. (2014)	https://doi.org/10.1007/s40692-014-0008-8
37	Maertens et al. (2014)	https://doi.org/10.1016/j.ijcci.2014.04.001
38	Pareto (2014)	https://doi.org/10.1007/s40593-014-0018-8
39	Kordaki (2011)	https://doi.org/10.1007/s10639-010-9136-6
40	Lowrie and Jorgensen (2011)	https://doi.org/10.1016/j.compedu.2011.06.010
41	Sun et al. (2011)	https://doi.org/10.1016/j.compedu.2011.05.022
42	Howard-Jones and Demetriou (2009)	https://doi.org/10.1007/s11251-008-9073-6
43	Bottino et al. (2007)	https://doi.org/10.1016/j.compedu.2006.02.003
44	Bragg (2007)	https://doi.org/10.1007/BF03217448
45	Sáenz-Ludlow (2006)	https://doi.org/10.1007/s10649-006-5760-x