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A Systematic Review of Digital Mathematics Game Articles Published in Peer-Reviewed Journals in Türkiye From 2005 to 2023

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Abstract

The current study aimed to provide a detailed synthesis of the literature on digital mathematics games and to gain an in-depth understanding of the current status of research on digital mathematics games. For this purpose, digital mathematics game articles published in peer-reviewed journals from 2005 to 2023 were systematically reviewed. To locate these articles, the following keywords were searched in TR Index, DergiPark Academic, and Google Scholar: “digital game”, “video game”, “computer game”, “interactive game”, “mobile game”, and “serious game”. The articles retrieved from the search were subjected to a two-stage screening process. First, the titles and abstracts of the articles were examined. Second, their full texts were examined. After the screening process, 26 articles that suited the purpose of the study were determined. Relevant data from the selected articles were extracted manually, recorded in an Excel spreadsheet, and finally synthesized. The findings were reported using the following research trends: (*i*) research aims, (*ii*) research methodologies, (*iii*) research participants, (*iv*) sample sizes, (*v*) designers of the digital mathematics games, (*vi*) environments used for designing digital mathematics games, and (*vii*) learning domains of the digital mathematics game topics. The findings are discussed based on the literature and implications for stakeholders are presented.

Key Words

Digital mathematics games • Peer-reviewed journal articles • Systematic literature reviews

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Introduction

A game can be defined as "a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome" (Salen & Zimmerman, 2004, p. 80). More specifically, digital games can be defined as games that are located on computers, mobile devices, game consoles (Becker, 2017; Jensen & Skot, 2022), and tablets (Jensen & Skot, 2022). Gredler (2004) argues that digital games are modernized versions of non-digital games that utilize advanced technology. However, although digital games share some similarities with non-digital games, they have evolved to become much more than their non-digital counterparts. For example, in digital games, the model of the original system must be meticulously and precisely defined, the rules must be fully decided in advance, the environment must be dynamic and the same for all players, and the interactions must remain consistent throughout all instances of the game, regardless of the location, time, or player (Becker, 2017).

Digital games can be categorized into two as educational games and commercial-off-the-shelf (COTS) games (Hu & Sperling, 2022). Educational games are games that are specifically designed to improve students' academic learning and boost their learning motivation (Mayer, 2014). The integration of educational games into instruction is a complex process that demands and necessitates substantial strategic preparation on the part of the instructor (Hu & Sperling, 2022). Moreover, educational games should be designed in accordance with the learning objectives of the school curricula (Ministry of National Education, [MoNE], 2023) or content or process standards (Council of Chief State School Officers, 2023). Therefore, instructors who want to use educational games in their classrooms must have sound specialized content knowledge (Hsu et al., 2013) and particular expertise in game-based teaching (Foster & Shah, 2020).

On the other hand, COTS games are created largely for enjoyment rather than academic instruction, they can be bought and used by the general public, but they are not specifically designed to meet the learning objectives or standards in school curricula (Ritzhaupt & Gunter, 2010). However, some COTS games include features from real-life environments and allow students to learn about the topics and skills traditionally taught in the classroom (Becker, 2017; Hu & Sperling, 2022). For instance, in middle school, Angry Birds can be employed to teach kinematics (Rodrigues & Carvalho, 2013). In high school, it can be employed to teach parabolas and vectors (Lamb, 2014). The SIMs and FIFA Soccer can be utilized for learning new languages (Purushotma, 2005; Wang, 2006). Furthermore, Assassin's Creed can be used for teaching the Renaissance period in history and social studies classrooms due to including correct historical information about this period (Starkey, 2015). Hence, COTS may be used in a variety of educational contexts as a complement to non-game teaching.

Digital games are new technologies that have advanced and interactive features and are continually designed, tried out, and advocated in educational environments (Hu & Sperling, 2022). They are sophisticated technologies that give players multifaceted experiences thanks to each game's distinct design and play mechanics (Ke, 2016). At the beginning of the twenty-first century, Prensky (2001) derived the phrase "digital game-based learning" (DGBL) based on the term "digital game". He broadly defined DGBL as any learning activity in which digital games are employed. However, Van Eck (2015) expanded on this definition and defined DGBL as "the use of games within an existing lesson, classroom, or other instructional contexts where the intent is at least as much to learn rather than to (exclusively) have fun" (p. 144). In the current study, I prefer to use the term "digital mathematics game" to refer to the digital game used in the course of learning mathematics. After Prensky's (2001) invention of the phrase "DGBL", the interest in digital mathematics games has grown dramatically within the mathematics education research community (e.g., Byun & Joung, 2018; Jensen & Skott, 2022; Joung & Byun, 2021; Yeo et al., 2022). With this increasing interest, over the past two decades, mathematics education researchers have been trying to figure out the instructional advantages of digital mathematics games on students' different kinds of learning outcomes such as cognitive learning outcomes (knowledge and skills), motor skills (acquisition and compilation), affective learning outcomes (attitude and motivation), and communicative learning outcomes (Wouters et al, 2009).

However, as articulated by several researchers (e.g., Ke, 2009; Kim & Chang, 2010; Monaghan, 2016), the literature on the effectiveness of digital games on students' learning outcomes is disconnected, inconsistent, and not well-organized. Ke (2009) further claimed that research on digital games must "take a systematic, comprehensive approach to examine dynamics governing the relations among multiple influential variables in a game-based learning system" (p. 24). The fragmentation and incoherency in the educational literature about digital games also seem to be the case for the literature on digital games in mathematics education. For instance, some researchers found out that digital mathematics games significantly impact students' mathematics achievement or performance (e.g., Bai et al., 2012; Beserra et al., 2014; Ke & Grabowski, 2007; Kebritchi et al., 2010; Kolovu et al., 2013), while some other researchers reported that digital mathematics games have a non-significant impact on students' mathematics achievement or performance (e.g., Carr, 2012; Ke, 2008a, 2008b, 2008c). Furthermore, several meta-analysis studies stressed that there is limited empirical evidence to support the effectiveness of digital mathematics games on students' cognitive learning outcomes (e.g., Byun & Joung, 2018; Wouters et al., 2013; Young et al., 2012).

Meanwhile, several researchers revealed that digital mathematics games have a significant impact on students' motivation to learn mathematics (e.g., Bai et al., 2012; Habgood & Ainsworth, 2011; Ke, 2008a) and attitude towards mathematics (e.g., Garneli et al., 2017; Ke & Grabowski, 2007; Ke, 2008a, 2008b, 2008c, Mavridis et al., 2017). In contrast, in some other research studies, it was reported that digital mathematics games do not significantly affect students' motivation to learn mathematics (e.g., Kebritchi et al., 2010) and attitude towards mathematics (e.g., Lopez-Morteo & Lopez, 2007; Pareto et al., 2012).

Last but not least, many researchers criticize that the digital mathematics games used in many articles are drill-and-practice games that do not develop students' higher-order thinking skills (e.g., Byun & Joung, 2018; Fox, 2000; Jensen & Skott, 2022; Larkin, 2015; Lowrie & Jorgensen 2015; Van Eck, 2015). For instance, Lowrie and Jorgensen (2015) expressed that "the vast majority of digital mathematics games are designed only to improve students' basic mathematics and literacy skills" and that these games "are not being used to promote higher-order thinking and deep learning, but rather visually appealing drill-and-practice games" (p. 5). Similarly, Byun and Joung (2018) stressed that such digital games are limited to the repetition of simple calculations and do not develop higher-level thinking skills, which are essential for solving more complicated mathematical problems. Moreover, Van Eck (2015) criticized that such digital games do not provide answers to "our current need to promote problem-solving, transfer of learning, and learning to think mathematically" (p. 144). Additionally, Fox (2000) indicated that such drill-and-practice games are a waste of time for students and argued that a sensitive mathematics teacher would not waste students' time "with pointless repetition of ideas that are already well assimilated" (p. 140).

Joung and Byun (2021) highlighted the importance of aligning the content of digital mathematics games with the process standards (i.e., problem-solving, reasoning and proof, communication, connections, and representations; National Council of Teachers of Mathematics, 2000) to promote higher-order thinking skills. In a recent systematic review study, Jensen and Skott (2022) focused on one of these process standards (i.e., mathematical reasoning) and attempted to understand how digital games might enhance students' development of mathematical reasoning based on the following reasons: (i) games can assist students in developing mathematical arguments, (ii) prior research reviews on digital mathematics games focused extensively on conceptual or procedural knowledge but not on specific processes, competences, or skills such as mathematical reasoning, and (iii) in the last twenty years, the importance of mathematical reasoning in elementary and middle school curricula has increased all over the world.

Based on the above-described explanations about and the contradictions and tendencies in the international literature on digital mathematics games, the current study attempted to provide a detailed synthesis of the national literature on digital mathematics games by conducting a systematic review of the peer-reviewed journal articles indexed in TR Index, DergiPark Academic, and Google Scholar.

Rationale and Research Questions

There are several rationales for conducting the current study. First, thus far, only a limited number of systematic literature reviews (meta-analyses in particular) have been conducted on digital mathematics games (e.g., Byun & Joung, 2018; Hussein et al., 2022; Tokaç et al., 2019; Uluçay & Çakır, 2014; Wouters et al., 2013; Yığ & Sezgin, 2021). Furthermore, research studies that conduct reviews on digital mathematics games in the national literature are almost non-existent. Indeed, after an extensive electronic database search and screening process, I could locate only 3 peer-reviewed journal articles two of which are systematic reviews (Uluçay & Çakır, 2014; Yığ & Sezgin, 2021) and one of which is a bibliometric analysis (Poçan, 2023). More specifically, Uluçay and Çakır (2014) systematically reviewed 37 journal articles, 8 dissertations, and 3 reports that were published between the years 2002 and 2012 indexed in Wiley Online Library, Science Direct, ACM Digital Library, ERIC (Education Resources Information Center), and Thesis Center of Turkish Council of Higher Education (Yükseköğretim Kurulu Başkanlığı Tez Merkezi). Meanwhile, Yığ and Sezgin (2021) systematically reviewed 71 peer-reviewed articles that were published from 2012 to 2019 in the Scopus database. Therefore, none of the two systematic literature reviews focused on peer-reviewed digital mathematics game articles in the national literature. Besides, Uluçay and Çakır (2014) reviewed dissertations and reports in addition to articles. Dissertations and reports are neither peer-reviewed nor formally published documents and, thus, are two specific types of grey literature (Jesson et al., 2011; Ridley 2012). Therefore, Uluçay and Çakır's (2014) systematic review might be lacking in methodological rigor due to including documents from the grey literature. For all these reasons, the national literature on digital mathematics games needs to be updated sooner through the conduction of systematic literature reviews focusing on peer-reviewed journal articles indexed in national databases.

Second, educational games are games that are specifically designed to improve students' academic learning and boost their learning motivation (Mayer, 2014). Moreover, educational games should be designed in accordance with the learning objectives of the school curricula (MoNE, 2023). Thus, focusing on the learning domains of the digital mathematics game topics used in the articles published in national databases is important. Knowing which learning domains are emphasized and which ones are deemphasized in published articles can make an important contribution to the integration of digital games into mathematics classrooms.

Third, according to Ke (2016), research on educational games has focused mainly on reporting on the learning effectiveness of these games without a comprehensive description of game design elements and processes. However, researchers have not paid sufficient attention to examining whether authors of the peer-reviewed articles design their digital games or use the digital games developed by others. Furthermore, in case the digital game is designed as part of the research, it is important to investigate which environments are used to design this game and whether research participants are involved in the game development process. Therefore, systematic reviews of digital mathematics game articles focusing on designers and game design environments deserve more attention from researchers.

Ultimately, the documents selected by Byun and Young (2018), Tokaç et al. (2019), Wouters et al. (2013), Uluçay and Çakır (2014), Yığ and Sezgin (2021), and Hussein et al. (2022) for their systematic reviews were published between years 2005 and 2014, 2008 and 2016, 1990 and 2012, 2012 to 2019, 2002 and 2012, and 2008 and 2019, respectively. However, a systematic review that examines digital mathematics game articles published between 2019 and 2023 is lacking in the literature. Therefore, it is significant to conduct a systematic review that examines all digital mathematics game articles published until 2023 in the national literature. In this way, it would be possible to extend the findings of previous systematic literature reviews on digital mathematics games (Byun & Joung, 2018; Hussein et al., 2022; Tokaç et al., 2019; Uluçay & Çakır, 2014; Wouters et al., 2013 Yığ & Sezgin, 2021) and it would help to draw a more accurate and consistent picture about digital mathematics games.

Due to the rationales and research gaps described above, in this study, I focused on summarizing the research trends on digital mathematics games in the national literature and thereby gained a deeper understanding of the current status of research in this area. Besides, I provided an updated and detailed synthesis of the digital mathematics games literature by extracting data also from peer-reviewed research articles published between 2019 and 2023 and incorporating them into the existing body of literature on digital mathematics games. All told, I attempted to find answers to the following in the current study:

(1) What are the current research trends on digital mathematics games in the national literature?

(a) What are the aims of the selected peer-reviewed articles?

(b) What are the research methodologies used in the selected peer-reviewed articles?

(c) What are the participants of the selected peer-reviewed articles?

(d) What are the sizes of the samples recruited in the selected peer-reviewed articles?

(e) What are the designers of the digital mathematics games in the selected peer-reviewed articles?

(f) What are the environments used for designing the digital mathematics games in the selected articles

(g) What are the learning domains of the digital mathematics game topics used in the selected articles?

The findings of the current study can be used to inform policy decisions and professional practice in the field of digital mathematics games.

As cautioned by Byun and Joung (2018), without a careful analysis of their impacts on different learning outcomes, integrating digital games into mathematics classrooms "may turn out to be a waste of time and resources" (p. 9) for students. This signals the significance of evidence-based practices (i.e., systematic literature reviews) in informing "policy decisions and professional practice" (Ridley, 2012, p. 189). The current systematic review study attempts to progress in this direction. Namely, this study prevents, to some extent, stakeholders including curriculum developers, digital game designers, mathematics educators, teachers, and students from making uninformed decisions based on a single study by offering a summary of the available evidence garnered from the national literature on digital mathematics games.

Methodology

Research Design

There are broadly three different types of literature reviews as systematic reviews, traditional-narrative reviews, and hermeneutic–phenomenological reviews (Efron & Ravid, 2019; Jesson et al., 2011). When these literature review types are placed on a continuum, systematic reviews stand on one end of the continuum, hermeneutic–phenomenological reviews stand on another end of the continuum, and traditional literature reviews stand between these two opposite literature review types (Efron & Ravid, 2019).

Torgerson (2003) argued that, in educational research, systematic literature reviews are better than other literature review types due to being more rigorous and adopting a more strict scientific methodology. Besides, Greetham (2021) argued that synthesizing and evaluating studies by using systematic literature reviews can highlight discrepancies in the findings and provide policymakers with the information they need to decide whether to implement, change, or abandon a policy. Following these arguments, in the current study, I used a systematic literature review (Efron & Ravid, 2019; Greetham, 2021; Jesson et al., 2011; Newman & Gough, 2020; Ridley, 2012) to provide a detailed synthesis of the national literature on digital mathematics games, to gain a deeper understanding of the current status of research on digital mathematics games in the national literature, and consequently to highlight several research gaps to be filled by future researchers in this area.

Systematic literature reviews provide a systematic and transparent method of obtaining, synthesizing, and assessing the quality of study findings on a certain topic or question and the goal is to reduce the bias inherent in single research and non-systematic reviews (Kahn et al., 2011). Systematic literature reviews have many other distinct characteristics. They entail a "rigorous, systematic, comprehensive, and exhaustive search for *all* the relevant literature"; they use "focused, explicit, transparent (replicable), standardized, structured, and protocol-driven methodologies", and finally they are "objective, balanced, and unbiased" (Jesson et al., 2011, p. 103).

Following Greetham's (2021) explanations, I attempted to improve the transparency and reproducibility of the current systematic review by providing a repeatable methodology, which is sufficient in detail and clarity. For conducting a more systematic and explicit review, I not only provided a repeatable methodology but also overtly explained what was done and why it was done. Finally, I set, defined, and justified my own inclusion and exclusion criteria for the peer-reviewed articles from which I extracted the relevant data to enhance the comprehensiveness of the current review.

Electronic Sources Used

Databases, electronic libraries, electronic journals, and Google Scholar are potential electronic resources for systematic searching (Jesson et al., 2011). In the current study, I used the following electronic sources when searching for the keywords related to digital mathematics games: TR Index (TR Dizin; https://trdizin.gov.tr), Dergipark Academic (DergiPark Akademik; https://dergipark.org.tr/tr/), and Google Scholar (Google Akademik; https://scholar.google.com.tr/). The reason for selecting these electronic sources when conducting keyword searches is explained in some detail in the following paragraphs.

TR Index is a national electronic database that includes articles published in national, peer-reviewed scientific journals in the disciplines of Natural and Social Sciences (The Scientific and Technological Research Council of Türkiye [TÜBİTAK], 2023a). TR Index was founded in Türkiye by the Turkish Academic Network and Information Center (Ulusal Akademik Ağ ve Bilgi Merkezi) to activate the production of academic knowledge, to expand information services on a national scale, and to create equal opportunities among researchers in accessing scientific information (TÜBİTAK, 2023b). My reason for using the TR Index is that it includes the list of academic journals in which researchers in Turkish institutions have to publish several peer-reviewed articles due to the requirements declared by The Inter-University Council for associate professorship applications (TÜBİTAK, 2023c). Therefore, it is believed TR Index covers high-quality journal articles that facilitate critical appraisals. It is important to note that critical appraisals help to assess the soundness of the methods and results of academic sources and consequently that they are fundamental for conducting sound systematic reviews (Petticrew & Roberts, 2006).

DergiPark Academic is a national publication portal for academic journal articles. It supports the existence of national academic journals in accordance with the standards and helps to increase the international visibility of these journals. (TÜBİTAK, 2023d). However, DergiPark Academic is not an electronic database. Rather, it is an infrastructure service that provides electronic hosting and editorial process management for all journals in Turkey that declare to be academic and refereed. Within the scope of DergiPark Academic, there are not only journals indexed in TR Index, Web of Science, Scopus, DOAJ, and other national/international indexes or platforms but also journals that have just started publishing peer-reviewed articles and that are not included in any index yet (TÜBİTAK, 2023e). Thus, I used DergiPark Academic in addition to the TR Index for locating peer-reviewed digital mathematics game articles that might have not been indexed in the TR Index yet. That is, DergiPark Academic helped me to retrieve digital mathematics game articles that are not indexed in the TR Index yet.

Google Scholar is an academic search engine that "provides a simple way to do a broad search for scholarly literature, including peer-reviewed papers, theses, books, abstracts, and articles" (Fraenkel et al., 2023, p. 56). It searches the whole internet by examining all of the material on millions of websites (Fraenkel et al., 2023). Therefore, my reason for using Google Scholar was that I wanted to widen my search outside of TR Index and DergiPark Academic to pick up more peer-reviewed articles on digital mathematics games and to locate the articles that are not displayed on TR Index and DergiPark Academic. To locate the journals and articles whose country of origin is Türkiye, I limited my search options only to "Turkish pages". However, Fraenkel et al. (2023) cautioned that Google Scholar must not be used in place of academic database searches. Therefore, I used Google Scholar results only as a complement to but not instead of TR Index and DergiPark Academic search results.

Keywords Searched in TR Index, DergiPark Academic, and Google Scholar

In the current study, to locate the peer-reviewed articles related to digital mathematics games, the following search terms (i.e., key words or key phrases) were formulated first: "oyun", "oyunlaştırma", "dijital", "video", "bilgisayar", "interaktif", "mobil", "ciddi", and "matematik". Second, the following key phrases were formulated through these key words: "dijital oyun", "video oyunu", "bilgisayar oyunu", "interaktif oyun", "mobil oyun", and "ciddi oyun". Third, using the Boolean operator "AND", these key phrases were combined with the term "matematik" to retrieve digital games articles that are related to mathematics. Finally, the following word combinations were searched in TR Index, DergiPark Academic, and Google Scholar: "dijital oyun" AND "matematik", "video oyunu" AND "matematik", "bilgisayar oyunu" AND "matematik", "interaktif oyun" AND "matematik", "mobil oyun" AND "matematik", and "ciddi oyun" AND "matematik".

Most of the peer-reviewed journals accessed through TR Index, DergiPark Academic, and Google Scholar published articles written in English as well. Therefore, to locate the digital mathematics game articles written in English, I conducted the same electronic search process described above and entered the following English equivalents of the aforementioned word combinations into TR Index, DergiPark Academic, and Google Scholar: "digital game" AND "mathematics", "video game" AND "mathematics", "computer game" AND "mathematics", "interactive game" AND "mathematics", "mobile game" AND "mathematics", and "serious game" AND "mathematics".

The electronic search began in January 2023 and continued until the last search in September 2023. To conduct an exhaustive search for all the relevant literature, I deliberately did not choose a cut-off date for the digital mathematics game articles published in peer-reviewed journals. Nevertheless, the electronic search results revealed that the oldest digital mathematics game article was published in 2005 while the most recent digital mathematics game article was published in 2023. Therefore, the current systematic review synthesized data from digital mathematics game articles published between the years 2005 and 2023.

After an initial search in the TR Index and DergiPark Academic, a total of 173 peer-reviewed articles on digital mathematics games were retrieved. Next, the duplicate articles and the ones that were not related to digital mathematics games were dropped and the total number of articles fell down to 78. These 78 peer-reviewed articles were subjected to a two-stage screening process. In the first stage, the titles and the abstracts of these peer-reviewed articles were examined. At the end of the first stage, 41 out of 78 peer-reviewed articles were identified as potentially relevant for further analysis. In the second stage, the full texts of the 41 articles were examined in detail. At the end of the second stage, it was found that 22 articles suited to the purpose of the current study and thus were included in the systematic review. Moreover, Google Scholar was searched manually and 4 peer-reviewed articles that were relevant to the focus of the present study were identified. Overall, 26 peer-reviewed articles on digital mathematics games (see Appendix) were included in the systematic review process.

Inclusion and Exclusion Criteria

To make sure that the articles retrieved from the electronic search are relevant to the purpose of the current review and consequently to conduct a rigorous systematic analysis, I used several inclusion and exclusion criteria. I applied the following inclusion criteria for selecting appropriate digital mathematics game articles:

1. The country of origin of the peer-reviewed journals must be Türkiye.

2. The full texts of the peer-reviewed journal articles must be accessible.

3. The peer-reviewed journal articles must be written either in Turkish or English.

4. The digital games used in the peer-reviewed journal articles must be related to the teaching and learning of mathematics.

5. The terms “game” or “oyun” must be included either in the title or abstract of the peer-reviewed articles.

I applied the following exclusion criteria for selecting appropriate digital mathematics game articles:

1. Peer-reviewed journal articles focusing on non-digital games

2. Peer-reviewed journal articles that focus both on digital and non-digital games

3. Peer-reviewed journal articles focusing on digital game addiction

4. Conference papers, book chapters, and dissertations (grey literature) focusing on digital mathematics games

5. Peer-reviewed journal articles whose main focus is on other technological tools

6. Peer-reviewed STEM education articles that do not primarily focus on digital games

7. Peer-reviewed journal articles that are only about information technologies or computer science

8. Non-English and non-Turkish peer-reviewed journal articles on digital mathematics games

Coding Scheme and Data Coding

The peer-reviewed articles given in the Appendix were analyzed using the inductive content analysis method. In this method, codes, categories, and themes emerge as a result of researchers’ long-term interaction with data (Patton, 2014). The codes used in the data coding process may come from the researcher himself/herself, from the literature, or the data set collected by the researcher (Yıldırım & Şimşek, 2008). In this systematic review, since there was no pre-established coding scheme through which the coders could categorize the data, the codes emerged from the data set that was collected by the author. Briefly speaking, in this study, a data-driven approach (Namey et al., 2008) was used for data coding.

The coding scheme was developed after a thorough examination of the peer-reviewed articles selected for the current systematic review. This scheme consists of the following seven major categories or research trends (*i*) research aims of the selected articles, (*ii*) research methodologies of the selected articles, (*iii*) research participants of the selected articles, (*iv*) sample sizes of the selected articles, (*v*) designers of the digital mathematics games in the selected articles, (*vi*) environments used to design digital mathematics games, and (*vii*) learning domains of the digital mathematics game topics used in the selected articles.

The coding of data was initiated after the development of the coding scheme. During the data coding process, relevant data from each article were extracted manually, recorded in an Excel spreadsheet, and finally synthesized. I and another researcher who has a doctoral degree in mathematics education and considerable experience in qualitative data analysis conducted the coding. We independently coded the data by using the constant comparison strategy (Corbin & Strauss, 2015). This strategy refers to the "analytic process of comparing different pieces of data against each other for similarities and differences" (Corbin & Strauss, 2015, p. 85). I used Miles and Huberman's (1994) reliability formula (i.e., $\text{reliability} = \frac{\text{the number of agreements}}{\text{the number of agreements + the number of disagreements}}$) to calculate the degree of agreement between the two coders. The inter-rater reliability between me and another researcher ranged between 78% and 89% for the seven research trends mentioned above. Miles et al. (2014) recommend obtaining at least 85% inter-rater agreement, depending on the "size and range of the coding scheme" (p. 85). Hence, we scheduled three meetings to collaborate, settle disagreements, and establish a coding consensus. At the end of the third meeting session, we had almost reached a complete agreement and had completed the data coding process.

Results

In this section, the findings are reported based on the following categories or research trends: (*i*) research aims, (*ii*) research methodologies, (*iii*) research participants, (*iv*) sample sizes (*v*) designers of the digital mathematics games, (*vi*) the environment used to design digital mathematics games, and (*vii*) learning domains of the digital mathematics game topics.

Aims of the Selected Articles

Aims of the selected articles regarding digital mathematics games and their frequencies are presented in Table 1.

Table 1

Aims of the selected articles regarding digital mathematics games

Aims of the selected articles	**Articles**	***f***
To reveal participants' views, experiences, and awareness about digital mathematics games	A1*, A3, A5*, A8*, A13, A14, A15, A17, A18, A20*, A24	11
To explore the impact of a digital game on a dependent variable (e.g., achievement, attitude, and spatial orientation skills)	A1*, A2, A5*, A6, A7, A8*, A10, A19, A20*, A21	10
To review the literature about digital mathematics games and gamification in mathematics education	A4, A16, A25	3
To reveal participants' views about the digital mathematics game design process	A9, A23	2
To evaluate digital mathematics games in the Education Information Network (EBA) or ABCya! application	A22, A26	2
To explore the impact of designing digital mathematics games on creativity	A12	1
To design and develop a digital mathematics game	A11	1

Note. Studies denoted with asterisks (*) explored both the impact of a digital game on a dependent variable and the participants' views about digital games or gamification.

As presented in Table 1, 11 out of 26 articles (42%) aimed to reveal participants' views, experiences, and awareness about digital mathematics games. For instance, A14 explored pre-service primary school teachers' experiences with a mobile game related to the Fundamental Theorem of Arithmetic. As another example, A17 presented the experiences and views of a primary school teacher and 20 third-grade students on gamification in the classroom using the mobile game "Hoverland".

Exploring the impact of a digital mathematics game on a dependent variable also received similar attention from the authors of the selected articles. Namely, 10 out of 26 articles (38%) aimed to explore the impact of a digital game on participants' cognitive and affective domain skills. For instance, A6 focused on the impact of computer games on fifth-grade students' achievement in four operations with natural numbers. To give another example, A21 investigated the impact of a mobile game on sixth-grade students' attitudes towards mathematics.

However, only 3 articles (12%) reviewed the literature on digital mathematics games and gamification in mathematics education. For example, A16 presented an exploratory holistic analysis of digital gamification in mathematics education by focusing on 71 peer-reviewed articles in the Scopus database. Moreover, only two articles revealed participants' views on the design process of digital mathematics games. To give an example, A9 examined pre-service teachers' digital mathematics game designs and their views on the digital game design process. Similarly, 2 articles (8%) aimed at evaluating digital mathematics games in EBA (A22) and the ABCya! application (A26). Finally, one article was published for each of the following aims: exploring the impact of designing digital mathematics games on creativity (A12) and designing and developing a digital mathematics game (A11).

Research Methodologies of the Selected Articles

The research methodologies of the selected articles related to digital mathematics games are presented in Table 2.

Table 2.

Research methodologies of the selected articles related to digital mathematics games

Research methodologies	**Articles**	***f***
Case study research	A3, A9, A13, A14, A15, A17, A18, A23	8
Experimental research	A2, A6, A7, A10, A12, A19, A21	7
Documentary research	A4, A16, A22, A25, A26	5
Mixed methods research	A1, A5, A8, A20	4
Phenomenological research	A24	1
Other	A11	1

As shown in Table 2, 8 out of 26 articles (31%) preferred case study research and 7 out of 26 articles (27%) preferred experimental research. Five articles (19%) preferred to use documentary research methodology and 4 articles (15%) preferred to use mixed methods research. On the other hand, the use of phenomenological research was very scarce. That is, only A24 used this research methodology. Finally, A11 designed and developed a digital mathematics game on transformation geometry (entitled "Simetri") and explained the design process of this game thoroughly. However, A11 did not report the research methodology used. Therefore, A11 was coded as "Other".

Participants of the Selected Articles

Participants of the selected articles related to digital mathematics games are presented in Table 3.

Table 3.

Participants of the selected articles

Participants of the selected articles	**Articles**	***f***
Middle school students (grades 5 – 8)	A1*, A2, A6, A7, A8, A20, A21	7
Primary school students (grades 1 – 4)	A1*, A5, A10, A17**, A19	5
Pre-service primary school teachers	A3, A12, A13, A14	4
Pre-service mathematics teachers	A9, A18, A23, A24	4
Primary school teachers	A17**	1
Mathematics teachers	A15	1
Does not involve human participants	A4, A11, A16, A22, A25, A26	6

*Fourth- and fifth-grade students, **third-grade students and a primary school teacher

As presented in Table 3, 7 articles (27%) were conducted with middle school students and 5 articles (19%) were conducted with primary school students. That is, 11 out of 26 articles (42%) were conducted with primary and middle school students (Note that A1 included both primary and middle school students as participants). Eight out of 26 articles (31%) were conducted with pre-service teachers, 4 with pre-service primary school teachers and 4 with pre-service mathematics teachers. However, authors of digital mathematics game articles seldom used in-service teachers as research participants. Namely, only A17 was conducted with primary school teachers and only A15 was conducted with mathematics teachers. The remaining 6 articles (23%) do not involve human participants. In more detail, A4, A16, and A25 are review studies related to digital mathematics games and gamification in mathematics education. As mentioned in the "Participants of the Selected Articles" subsection, A11 designed a digital mathematics game entitled "Simetri". However, it did not empirically test its effectiveness with learners. Therefore, A11 did not involve human participants. Lastly, A22 is documentary research that examined the middle school level digital mathematics games in EBA based on the Bloom taxonomy and A26 is another documentary research that examined the games in ABCya! application (https://www.abcya.com/) based on the learning trajectories for the development of number concepts. Thus, these articles did not include human participants as well.

Sample Sizes in the Selected Articles

Sample sizes in the selected articles related to digital mathematics games are presented in Table 4.

Table 4.

Sample sizes in the selected articles

Sample sizes	**Articles**	***f***
Between 5 and 10	A15, A3	2
Between 11 and 20	A13, A24, A14, A19	4
Between 21 and 30	A17, A20, A12, A18, A21, A7, A9	7
Between 31 and 40	A23	1
Between 41 and 50	A1, A5, A6, A8	4
Between 100 and 150	A10	1
Between 150 and 200	A2	1
Does not involve human participants	A4, A11, A16, A22, A25, A26	6

Note. In the "Articles" column, the articles are listed from smallest to largest in terms of their sample sizes.

As can be calculated from Table 4, in 11 out of 26 articles (42%), the sample size was between 11 and 30. More specifically, there are 7 studies (27%) with a sample size between 21 and 30 participants and 4 studies (15%) with a sample size between 11 and 20. Likewise, there are 4 studies (15%) with a sample size between 41 and 50 participants. On the other hand, the remaining sample sizes reported in Table 4 were less frequently preferred by the articles. In other words, A3 and A15 had a sample size between 5 and 10, A23 had a sample size between 31 and 40, A10 had a sample size between 100 and 150, and finally A2 had a sample size between 150 and 200. As mentioned in the "Participants of the Selected Articles" subsection, A4, A11, A16, A22, A25, and A26 do not include human participants. Therefore, sample sizes were naturally not reported in these articles.

Designers of the Digital Mathematics Games in the Selected Articles

Designers of the digital mathematics games in the selected articles are presented in Table 5.

Table 5.

Designers of the digital mathematics games in the selected articles

Designers of the digital game		**Articles**	***f***
Designed within the scope of the study	Designed by the researcher	A2, A7, A10, A11, A13, A14, A21	7
	Designed by the participants	A9, A12, A23, A24	4
	Designed by individuals who are not actual participants	A15	1
Taken directly from online sources	Taken directly from the Internet or digital game development companies	A1, A3, A6, A17, A18, A19, A20, A26	8
	Taken directly from the educational content network entitled EBA	A8, A22	2
	Taken directly from the online educational platform entitled Vitamin	A5	1
Not Applicable		A4, A16, A25	3

As shown in Table 5, the digital mathematics games used in the selected articles were either created (n = 12, 46%) or directly taken from online sources (n = 11, 42%). The digital mathematics games in the first category were either created by the authors of the articles, research participants, or individuals who were not actual research participants (n = 1, 4%). In more detail, the digital mathematics games in 7 articles (27%) were designed by the researchers. For instance, in A13, the researchers designed a digital game to introduce the Euclid Division to pre-service primary school teachers by using the Java language in the Android Studio environment. In 4 articles (15%), the digital mathematics games were designed by the research participants. To give an example, A23 aimed to provide pre-service middle school mathematics teachers with the experience of designing digital games, to explore their opinions, and to evaluate the games they designed. Within the scope of A23, pre-service middle school mathematics teachers designed their digital games by using an application called Draw Your Game, which can be downloaded for free from Playstore or App Store. The digital mathematics games in 1 article (A15; 4%) were designed by individuals who are not actual participants. That is, A15 explored in-service mathematics teachers' views on the digital mathematics games designed by pre-service mathematics teachers using Scratch. The pre-service teachers designed 13 digital mathematics games related to algebraic expressions and then six middle school mathematics teachers evaluated these digital games by using rubrics.

The digital mathematics games in the second category were either taken from the internet and game development companies, educational platforms, or content networks. In more detail, the digital mathematics games in 8 articles (31%) were taken directly from the internet or digital game development companies. For example, A18 used the online game Monty Hall Simulation, which was provided by a mathematics website. Moreover, in 2 articles (A8 and A22; 8%), the researchers used digital mathematics games delivered through the educational content network entitled EBA. For instance, in A22, which is an example of documentary research, the researchers evaluated the middle school mathematics games included in EBA based on Bloom's taxonomy.

The Environments Used to Design Digital Mathematics Games in the Selected Articles

The environments used to design digital mathematics games in the selected articles are presented in Table 6.

Table 6.

The environments used to design digital mathematics games in the selected articles

The environments used to design digital mathematics games	**Articles**	***f***
Scratch	A9, A15, A24	3
Android Studio	A13, A14	2
C#	A10	1
Construct 2	A11	1
Draw your game	A23	1
Not mentioned	A2, A7, A12, A21	4
The digital mathematics games were designed previously by other researchers, institutions, or organizations	A1, A3, A5, A6, A8, A17, A18, A19, A20, A22, A26	11
Not Applicable	A4, A16, A25	3

As shown in Table 6, one of the environments used to design digital mathematics games in the selected articles is Scratch. 3 articles (12%) preferred to use the Scratch program to design digital mathematics games. For instance, A24 explored pre-service teachers' awareness of digital games. In A24, pre-service teachers designed digital mathematics games using Scratch. In 2 articles (A13 and A14; 8%), the researchers preferred to use the Android Studio to design digital mathematics games. For instance, in A14, the researchers designed the Bacterial Colony Game by using Android Studio to investigate pre-service teachers' exploration of the Fundamental Theorem Of Arithmetic through a mobile game.

In one article (3%), the researchers used C# for designing digital games. Namely, in A10, the researchers designed a snake game using the C# programming language. In another article (A11; 3%), the researchers designed and developed a digital mathematics game on transformation geometry by using Construct 2. Finally, in A23 (3%), pre-service mathematics teachers designed digital games by using the program entitled Draw Your Game.

As demonstrated in Table 6, in 4 articles (15%), the researchers did not explicitly mention the name of the environment they used to design the digital games. The digital mathematics games used in 11 articles (42%) had previously been designed by other researchers, institutions, or organizations. Last, 3 articles (12%) reviewed the literature on digital mathematics games and gamification in mathematics education and they did not include digital mathematics games.

Learning Domains of the Digital Mathematics Game Topics Used in the Selected Articles

Learning domains of the digital mathematics game topics used in the selected articles are presented in Table 7.

Table 7.

Learning domains of the digital mathematics game topics used in the selected articles

Learning domains	**Articles**	***f***
Numbers and operations	A1, A2, A3*, A5, A6, A7, A8, A10, A13, A14, A17**, A19, A21, A26	14
Multiple learning domains	A9, A12, A22, A23, A24	5
Geometry	A11, A17**, A20	3
Measurement	A3*	1
Algebra	A15	1
Not indicated	A18	1
Not Applicable	A4, A16, A25	3

Note. *A3 selected mathematical topics from both Numbers and Operations and Measurement learning domains. **A17 selected mathematical topics from both Numbers and Operations and Geometry learning domains

As presented in Table 7, in more than half of the articles (*n* = 14; 54%) the mathematical topics of the digital games were selected from the Numbers and Operations learning domain. For instance, A1 investigated the effect of educational computer games on students' arithmetical operation skills. Similarly, in A2, the effects of educational computer games on students' attitudes towards mathematics and educational computer games were investigated and the authors developed two games called "Proportional Tetris" and "Proportional Clown" related to the topic of ratio-proportion for seventh-grade students.

In 5 articles (19%), the digital mathematics game topics were from multiple learning domains. However, in very few articles the topics of the digital games were selected from Geometry (*n* = 3; 12%), Algebra (*n* = 1, 4%), and Measurement (*n* = 1, 4%) learning domains. For instance, A11 developed a digital game on transformation geometry. A20 investigated the effect of the video game Euro Truck Simulator 2 on the spatial orientation and entrepreneurial skills of gifted children. In A15, pre-service teachers designed digital mathematics games related to algebraic expressions. None of the articles reviewed in the current study used digital games that were directly related to data analysis and statistics. Last, A18 did not explicitly indicate the learning domain from which the mathematical topic of the digital game was selected.

Discussion and Implications

The current study attempted to provide a detailed synthesis of the literature on digital mathematics games by conducting a systematic review of the peer-reviewed journal articles whose country of origin is Türkiye. The selected articles were synthesized by considering the following research trends: research aims, research methodologies, research participants, sample sizes, designers of the digital mathematics games, environments used to design the digital mathematics games, and the learning domains of the digital mathematics game topics. In the following paragraphs, the findings are discussed based on these research trends.

Research Aims

The results of this study showed that nearly half of the articles aimed to reveal learners' views, experiences, and awareness about digital mathematics games (*n* = 11; 42%). A partial explanation for the interest in this trend is that the authors might have preferred to conduct research on digital mathematics games based on research gaps in this area. However, this trend was much less evident in the study of Byun and Joung (2018). They selected 33 digital mathematics game articles from EBSCOhost Online, ERIC, PsycINFO, Social Science Citation Index, and Science Citation Index and found that only one article (3%) examined participants' perceptions and thoughts about digital mathematics games.

Similarly, less than half of the articles aimed to examine the impact of digital mathematics games on learners' achievement, attitude, and spatial orientation skills (*n* = 10; 38%). A plausible explanation for this trend is that the authors might have believed that merely exploring learners' views, experiences, and awareness about digital mathematics games may not resolve the current issues about digital mathematics games and the effectiveness of these games in mathematics instruction and this belief might have encouraged them to identify these issues and test the impacts of digital mathematics games on students' different learning outcomes. Previous systematic review studies on digital mathematics games (e.g., Byun and Joung, 2018; Pan et al., 2022) also pointed out the need for testing the educational effectiveness of digital mathematics games. For instance, Pan et al. (2022) examined how games are utilized for mathematics learning and identified game design aspects that improved effective mathematics learning. To retrieve the appropriate articles that met their goal, they searched in JSTOR, ERIC, EBSCO, Psych Info, Dissertation Abstracts, and ACM. They revealed that previous review studies lacked essential and contextual information about the features and strategies used in game design that control how learning and gameplay are integrated.

On the other hand, the current study showed that conducting literature reviews (*n* = 3, 12%), identifying learners' views about mathematics game design processes (*n* = 2, 8%), evaluating the digital mathematics games delivered through EBA or ABCya! application (*n* = 2, 8%), examining the effect of designing digital mathematics games on creativity (*n* = 1, 4%), and developing digital mathematics games (*n* = 1, 4%) received scant attention from the authors of the digital mathematics game articles. The lack of research on learners' views, experiences, and evaluations of mathematics game design processes was also stressed in previous research studies (e.g., Aldemir Engin, 2022; Ke & Abras, 2013; Ke, 2016; Pan et al., 2022; Yıldız Durak & Karaoğlan Yılmaz, 2019). Pan et al. (2022) contended that there is still a dearth of empirical and theoretical research on the impact of digital game design and usage on students' learning of mathematics. Ke (2016) complained that educational game researchers focused mainly on reporting on the learning effectiveness of games without a comprehensive description of game design elements and processes. She recommended that researchers should present a phenomenological account of their experiences in creating educational games, focusing on the theoretical underpinnings, general design principles, design rationale for game mechanics and game world design, as well as important takeaways and suggestions.

Research Methodologies

In this study, it was found that authors of the digital mathematics game articles used case studies (*n* = 8, 31%) and experimental research designs (*n* = 7, 27%) more prevalently when compared to mixed methods (*n* = 4, 15%), documentary (*n* = 5, 19%), and phenomenological research designs (*n* = 1, 4%). The popularity of case study designs in the selected articles can be attributed to the fact that the authors attempted to match the aims of their studies with relevant research designs. That is, the authors of A3, A13, A14, A15, A17, and A18 explored in-depth learners' views, experiences, and awareness about digital mathematics games, while the authors of A9 and A23 explored participants' views about digital mathematics game design process and to achieve their purposes, these authors used a case study design as this research methodology best suits their research goals.

Previous systematic reviews reported similar findings with respect to experimental research designs and found that the majority of the selected articles on digital mathematics games adopted this research design as their research methodologies (e.g., Byun & Joung, 2018; Pan et al., 2022). Byun and Joung (2018) revealed that 30 out of 33 digital mathematics game articles (91%) used quantitative and mixed methods research designs while only three articles (9%) used qualitative research designs. Similarly, Pan et al. (2022) reviewed digital mathematics game articles using both experimental and non-experimental research designs and found that 40 out of 43 articles (93%) used experimental research designs, while two of them (4.6%) used qualitative research designs and one of them (2.4%) used a design-based research methodology. Furthermore, Yığ and Sezgin (2021) reviewed 71 peer-reviewed articles in the SCOPUS database to uncover the main problems, intentions, and trends in digital mathematics games and they found that in 28 out of 71 articles (39%), experimental designs were used as research methodologies

The fact that experimental study designs were most frequently used as research methodologies in the selected articles on digital mathematics games may be ascribed to the fact that only in experimental studies it can be ascertained that the observed results on students' critical learning outcomes (e.g., mathematics achievement) in an experiment are produced by the treatment (e.g., a certain teaching approach, a newly established curriculum, or an instructional program) but not by extraneous factors (Avcu & Avcu, 2022). Another plausible explanation for the common use of experimental designs is that studies with such methodologies have a great impact on the educational policies and practices implemented in all countries around the world (Borman et al., 2005; Slavin, 2008). Besides, researchers are increasingly encouraged to conduct studies with more rigorous methodological designs such as randomized controlled trials to benefit from the funding opportunities provided by public or private agencies (Hedges & Schauer, 2018).

On the contrary, the findings of this study indicated that survey research methodology was not preferred by the authors of the selected articles on digital mathematics games. Pan et al. (2022) also reported that they did not review any article that uses a survey design. Additionally, Yığ and Sezgin (2021) revealed that, of the 71 peer-reviewed articles on digital mathematics games, only one of them (1%) used survey research methodology. However, survey studies have many advantages since they are relatively simple to administer; are cost-effective; enable gathering information from a huge number of people in a very limited time; can be conducted remotely through e-mails, telephones, and mobile devices; provide a great deal of freedom for data analysis; and enable collection of a wide variety of data including attitudes, opinions, beliefs, values, behaviors, and facts (Cohen et al., 2018; Mills & Gay, 2019). Therefore, digital game researchers should conduct many survey studies to reveal a large number of teachers' views, experiences, and evaluations about the application of digital mathematics games in mathematics classrooms. In this way, it can be understood how and to what extent digital games are integrated into teachers' mathematics teaching practices in real classroom settings.

Research Participants

The findings showed that digital mathematics game authors recruited pre-service teachers, middle school students, primary school students, and in-service teachers as research participants in eight (31%), seven (27%), five (20%), and two articles (8%), respectively. However, the systematic literature review on digital mathematics games appears to be contradictory in terms of the educational background of research participants (e.g., Byun & Joung, 2018; Hussein et al., 2022; Pan et al., 2022; Tokaç et al., 2019; Uluçay & Çakır, 2014; Yığ & Sezgin, 2021). For instance, Uluçay and Çakır (2014) systematically reviewed articles, dissertations, and reports indexed in Wiley Online Library, Science Direct, ACM Digital Library, ERIC, and Thesis Center of Turkish Council of Higher Education and reported that in the digital mathematics game studies they reviewed, middle school students (n = 18, 42%) were the most frequently recruited research participants compared to primary school students (n = 10, 23%), high school students (n = 4, 9%), pre-school students (n = 3, 6%), and university students (n = 3, 6%). On the other hand, other systematic review studies found that primary school students were the most frequently recruited research participants in reviewed the digital mathematics game articles (Byun & Joung, 2018; Hussein et al., 2022; Pan et al., 2022; Tokaç et al., 2019; Yığ & Sezgin, 2021). In more detail, 30 out of 43 studies (70%) in Hussein et al. (2022), 22 out of 33 studies (66%) in Byun and Joung (2018), 16 out of 24 studies (66%) in Tokaç et al. (2019), 20 out of 43 studies (46%) in Pan et al. (2022), and 24 out of 65 studies (37%) in Yığ and Sezgin (2021) used primary school students as research participants.

Hussein et al. (2022) employed the Social Sciences Citation Index to find digital game-based learning interventions in mathematics education. As argued by Hussein et al. (2022), one possible reason for the authors' recruitment of primary and middle school students but not high school students as research participants in the digital mathematics game articles selected for the current study is that digital games may naturally be more enjoyable and pleasant for primary and middle school students than for high school students. Additionally, digital mathematics game researchers might be opting to concentrate on primary and middle school students since these students are less burdensome and easier to please than high school students who would need complex and advanced digital game-based learning applications.

It is important to note that in the current systematic review, only two articles on digital mathematics games selected in-service teachers as research participants. For this reason, conducting digital mathematics game research with in-service teachers as study participants may play an essential but partial role in closing the research gap in the digital mathematics games literature.

Sample Sizes

In this study, the findings indicated that in one article (A2, 4%) the number of participants ranged between 150 and 200; in another article (A10, 4%) the number of participants ranged between 100 and 150; in four articles (15%) the number of participants ranged between 41 and 50; in one article (A23, 4%) the number of participants ranged between 31 and 40; in seven articles (27%) the number of participants ranged between 21 and 30; in another four articles (15%) the number of participants ranged between 11 and 20; and finally, in two articles (4%) the number of participants ranged between 5 and 10. Note that I reviewed only two articles (A2, A10; 8%) in which there were more than 50 participants. This finding appears contradictory to the findings of Pan et al. (2022) who reported that 34 out of 43 articles (79%) reviewed in their study had medium to large sample sizes ranging between 50 and 435. More specifically, Pan et al. (2022) revealed that 9 out of 43 articles (20.9%) had a sample size of less than 50, 23 articles (53.5%) had a sample size ranging between 50 and 200, and 11 articles (25.6%) had a sample size ranging between 200 and 435.

In this study, in seven case study articles (A3, A9, A13, A14, A15, A17, and A18; 27%) the number of participants ranged between 5 and 30. This finding is not surprising since qualitative research studies are often carried out with small samples of less than 30 individuals (Pan et al., 2022). Despite this, in one case study article (A23, 4%) 39 middle school mathematics teachers were selected as study participants. Additionally, in one phenomenological research article (A24; 4%) the number of participants ranged between 11 and 20. Therefore, it can be suggested that the authors of qualitative research articles on digital mathematics games were often inclined to match their research methodologies with relevant sample sizes.

On the other hand, in four digital mathematics game articles that used experimental research design methodology (A7, A12, A19, and A21; 15%), the sample size was less than 30. This means that there were less than 30 participants in each of their experimental and control groups. The authors of widely used educational research textbooks (e.g., Ary et al., 2014; Fraenkel et al., 2023; Mills & Gay, 2019) proposed that each cell or group (i.e., experimental and control groups) should include at least 30 participants. This cut-off value is particularly significant for experimental research designs because a sample size of less than 30 for each group may result in insufficient statistical power and consequently may jeopardize the validity of the experimental study (Cheung & Slavin, 2012). Therefore, authors of the experimental research articles on digital mathematics games should recruit a considerably greater number of participants in their studies (i.e., at least a total of 60 participants) to improve the statistical power of their studies and eliminate Type I and Type II errors.

Designers of the Digital Mathematics Games and Environments Used to Design the Digital Mathematics Games

The findings of this study demonstrated that the digital mathematics games used in the selected articles were either created (n = 12, 46%) or directly taken from online sources (n = 11, 42%). The digital mathematics games in the first category were either created by the authors of the articles (n = 7, 27%), research participants (n = 4, 15%), or individuals that were not actual research participants (n = 1, 4%). The digital mathematics games in the second category were either taken from the internet and game development companies (n = 8, 27%), educational platforms, or content networks entitled EBA and Vitamin (*n* = 3, 12%). The finding that the authors of the selected articles preferred to create their digital mathematics games rather than rely on pre-existing digital mathematics games is supported by Pan et al. (2022) who uncovered that more researchers favored developing a new game from Scratch or modifying an existing game (*n* = 22, 51%) than adopting from existing games depending on the research goals (*n* = 19, 44%). However, this finding is somewhat in contrast with the findings of Tokaç et al. (2019) who searched in ERIC, PsycINFO, Wilson, Google Scholar, JSTOR, and ISI Web of Science databases to locate the peer-reviewed journal articles, book chapters, dissertations, and conference papers that focused on the impacts of computer games on students' achievement in mathematics. They demonstrated that in 9 out of 24 studies reviewed (37.5%), the digital games were developed by the study authors, while in the remaining 15 studies (62.5%) the digital games were pre-existing games already developed by other individuals or institutions (i.e., DimensionM, iPad math games, Slope game, Gem game, Brain Age 2, MySims, Astra Eagle, VmathLive, Sims 2–Open for Business, Chartworld, Skills Arena, Lure of the Labyrinth, and Goldilocks series games).

It is desirable that the digital mathematics games used in empirical research studies are designed by the authors or participants of these studies. Providing the study participants with the opportunity to create or modify digital mathematics games and involving them in digital game design processes is extremely crucial because, as emphasized by Tokaç et al. (2019), one aspect influencing the relationship between "digital game-based learning" and "mathematics achievement" is the design characteristics of digital mathematics games. Therefore, future researchers may concentrate more on how and why design futures of digital mathematics games influence students' different learning outcomes such as mathematics achievement, attitudes towards mathematics, or motivation to learn mathematics.

Another important finding of the present study is that three articles (A9, A15, and A24; 12%) used the Scratch programming language, two articles (A13 and A14; 8%) used the Android Studio application, one article (A10; 4%) used the C# programming language, another article (A11; 4%) used the Construct 2 digital game engine, and finally one another article (A23; 4%) used the Draw Your Game application as environments used for designing digital mathematics games. Unfortunately, this research trend has not been examined in many of the existing systematic literature reviews (e.g., Byun & Joung, 2018; Hussein et al., 2022; Pan et al., 2022; Tokaç et al., 2019; Uluçay & Çakır, 2014; Wouters et al., 2013; Yığ & Sezgin, 2021). Therefore, research that explores how digital games that are designed in different environments contribute to students' mathematics achievement or attitude is warranted to fill the aforementioned research gap in the literature on digital games.

Learning Domains of the Digital Mathematics Game Topics

In this study, in more than half of the articles (*n* = 14; 54%) the mathematical topics of the digital games were selected from the Numbers and Operations learning domain. In previous literature review studies, it was also reported that the reviewed articles selected the topics of their digital games mostly from Numbers and Operations learning domain (e.g., 29 out of 43 articles [67%] in Hussein et al., 2022; 15 out of 23 digital mathematics games [65%] in Joung & Byun, 2021; 24 out of 43 articles [56%] in Pan et al., 2022; and 16 out of 33 articles [48%] in Byun & Joung, 2018).

On the other hand, it was found in this study that in very few articles the topics of the digital games were selected from Geometry (*n*=3; 12%), Algebra (*n* = 1, 4%), and Measurement (*n* = 1, 4%) learning domains. As was the case in the present study, in some review studies, it was revealed that the topics of the digital games were selected less frequently from Geometry learning domain (e.g., 7 studies [21%] in Byun & Joung, 2018; 3 digital games [13%] in Joung & Byun, 2021; 3 studies [%7] in Pan et al., 2022; and one study [%2] in Hussein et al., 2022). However, in these review studies, it was also found that the topics of the digital games were selected more frequently from the Algebra learning domain compared to the present study findings (e.g., 12 studies [36%] in Byun & Joung, 2018; 6 studies [26%] in Joung & Byun, 2021; and 5 studies [11%] in Hussein et al., 2022). Similar to the present study findings, Joung and Byun (2021) found that only in 3 out of 23 digital games (13%) the mathematical topic was selected from the Measurement learning domain while Byun and Joung (2018) found that in only 5 out of 33 articles (15%) the mathematical topics of the digital games were selected from this learning domain.

It is worthy of note that in none of the articles reviewed in the current study, the mathematical topics of the digital games were selected from the Data Analysis and Probability learning domain. This was also the case in the studies of Joung and Byun (2021) and Hussein et al. (2022). Meanwhile, Byun and Joung (2018) reported that they reviewed only one article (2.3%) in which the mathematical topic of the digital game was selected from the Data Analysis and Probability learning domain.

With respect to the learning domains from which the mathematical topics were selected, the present study findings demonstrated that authors of the digital mathematics game articles showed particular interest in Numbers and Operations. One possible explanation for this interest is that the Numbers and Operations learning domain forms the basis of other learning domains and is fundamental for improving students' achievement in mathematics (Geary, 2011). In more detail, in many school mathematics curricula (e.g., Common Core State Standards for Mathematics, 2010; MoNE, 2018) mathematical topics from the Numbers and Operations learning domain are introduced first to the students. After developing their essential understanding of mathematical topics in the Numbers and Operations learning domain, the students are expected to extend and transfer these understandings to the other learning domains and thereby develop a better understanding of a wide variety of mathematical topics from all learning domains.

Ultimately, based on the findings explained above, it can be recommended that researchers design digital games for teaching mathematical topics related to Data Analysis and Probability, Algebra, Measurement, and Geometry learning domains and delve deeper into the reasons for the lack of digital mathematics games in these domains.

Ethics

The current study is a systematic review of digital mathematics games and does not involve human participants. Therefore, ethical approval is not required in this study.

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Appendix: Peer-Reviewed Journal Articles Selected for the Systematic Review

In this section, digital mathematics game articles published in national peer-reviewed journals from 2005 to 2023 are listed.

Article IDs	References
A1	Kula, A., & Erdem, M. (2005). The effect of educational computer games on the development of basic arithmetical operation skills. *Hacettepe Üniversitesi Eğitim Fakültesi Dergisi*, *29*, 127–136.
A2	Çankaya, S. ve Karamete, A. (2008). Eğitsel bilgisayar oyunlarının öğrencilerin matematik dersine ve eğitsel bilgisayar oyunlarına yönelik tutumlarına etkisi. *Mersin Üniversitesi Eğitim Fakültesi Dergisi*, *4*(2), 115–127.
A3	Topçu, H., Küçük, S. ve Göktaş, Y. (2014). Sınıf öğretmeni adaylarının ilköğretim matematik öğretiminde eğitsel bilgisayar oyunlarının kullanımına yönelik görüşleri. *Turkish Journal of Computer and Mathematics Education*, *5*(2), 119–136. https://doi.org/10.16949/turcomat.09768
A4	Uluçay, İ. S. ve Çakır, H. (2014). İnteraktif oyunların matematik öğretiminde kullanılması üzerine araştırmaların incelenmesi. *Eğitim Teknolojisi Kuram ve Uygulama*, *4*(1), 13–34. https://doi.org/10.17943/etku.21297
A5	Aslan Akın, F. ve Atıcı, B. (2015). Oyun tabanlı öğrenme ortamlarının öğrenci başarısına ve görüşlerine etkisi. *Turkish Journal of Educational Studies*, *2*(2), 75–102.
A6	Sayan, H. (2015). The effects of computer games on the achievement of basic mathematical skills. *Educational Research and Reviews*, *10*(22), 2846–2853.
A7	Aktaş, M., Bulut, G. G. ve Akbaş, B. K. (2018). Dört işleme yönelik geliştirilen mobil oyunun 6. sinif öğrencilerinin zihinden işlem yapma becerisine etkisi. *Eğitim ve Toplum Araştırmaları Dergisi*, *5*(2), 90–100.
A8	Türkmen, G. P. & Soybaş, D. (2019). The effect of gamification methodology on students' achievements and attitudes towards mathematics. *Bartın University Journal of Faculty of Education*, *8*(1), 258–298. https://doi.org/10.14686/buefad.424575
A9	Yıldız Durak, H. ve Karaoğlan Yılmaz, F. G. (2019). Öğretmen adaylarının matematik öğretimine yönelik eğitsel dijital oyun tasarımlarının ve tasarım sürecine ilişkin görüşlerinin incelenmesi. *Ege Eğitim Dergisi*, *20*(1), 262–278. https://doi.org/10.12984/egeefd.439146
A10	İncekara, H., & Taşdemir, Ş. (2019). The design of a digital game for developing four operations skills in mathematics and its effects on student success. *Gazi Mühendislik Bilimleri Dergisi*, *5*(3), 227–236. https://doi.org/10.30855/gmbd.2019.03.03
A11	Navruz, M., & Taşdemir., Ş. (2019). Design and development of an educational digital game based on mathematics course transformation geometry. *International Journal of Applied Mathematics Electronics and Computers*, *7*(4), 88–95. https://doi.org/10.18100/ijamec.597156
A12	Aksoy, N. C. ve Küçük Demir, B. (2019). Matematik öğretiminde dijital oyun tasarlamanın öğretmen adaylarının yaratıcılıklarına etkisi. *Gazi Üniversitesi Gazi Eğitim Fakültesi Dergisi*, *39*(1), 147–169. https://doi.org/10.17152/gefad.421615
A13	Gök, M., İnan, M. ve Akbayır, K. (2020). Sınıf öğretmeni adaylarına Öklid bölmesinin bir mobil oyunla tanıtılması. *Cumhuriyet International Journal of Education*, *9*(1), 219–242. http://dx.doi.org/10.30703/cije.560761
A14	Gök, M. (2020). Sınıf öğretmeni adaylarının bir mobil oyun deneyimi: Aritmetiğin temel teoremi. *Journal of Computer and Education Research*, *8*(15), 41–74. https://doi.org/10.18009/jcer.643732

A15	Gökkurt Özdemir, B., Basır, R., Balbay, A., Meredova, P., & Çağlar, K. (2021). Digital games designed by prospective teachers in the scratch program through the eyes of mathematics teachers. *International Journal on Lifelong Education and Leadership*, *7*(2), 37–58. https://doi.org/10.25233/ijlel.994301
A16	Yığ, K. G., & Sezgin, S. (2021). An exploratory holistic analysis of digital gamification in mathematics education. *Journal of Educational Technology and Online Learning*, *4*(2), 115–136. https://doi.org/10.31681/jetol.888096
A17	Kara, N. (2021). Eğitsel mobil matematik oyunu ile sınıf içi oyunlaştırma: Bir durum çalışması örneği. *Muğla Sıtkı Koçman Üniversitesi Eğitim Fakültesi Dergisi,* *8*(1), 85–101. https://doi.org/10.21666/muefd.764044
A18	Koparan T., (2021). Yükseköğretimde dijital oyun tabanlı öğrenme ortamından yansımaların incelenmesi. *Yükseköğretim ve Bilim Dergisi,* *11*(3), 503–515. https://doi.org/10.5961/jhes.2021.470
A19	İşmarcı, Z. ve Yeşilyurt, M. (2021). Web tabanlı oyunun onluğa yuvarlamaya etkisi. *New Era Journal of Interdisciplinary Social Studies*, *6*(8), 113–121. http://dx.doi.org/10.51296/newera.61
A20	Yılmaz, E., Yıldırım, Y. & Arıkan, A. (2022). Exploring the effect of video games on gifted children's spatial orientation and entrepreneurial skills. *E-International Journal of Educational Research*, *13*(5), 238–257. https://doi.org/10.19160/e-ijer.1150405
A21	Aktaş, M., Bulut, G.G. ve Aktaş, B. K. (2022). Ortaokul 6. sınıf öğrencilerinin zihinsel işlem becerilerini artırmaya yönelik geliştirilen mobil oyunun öğrencilerin matematik dersine yönelik tutumlarına etkisi, *International Social Mentality and Researcher Thinkers Journal*, *8*(61), 1258–1264. https://doi.org/10.29228/smryj.63594
A22	Günbaş, N. ve Öztürk A., N. (2022). Eğitim Bilişim Ağı (EBA) içeriklerinde yer alan dijital matematik oyunlarının Bloom taksonomisine göre incelenmesi. *e- Kafkas Eğitim Araştırmaları Dergisi*, *9*(1), 253–278. https://doi.org/10.30900/kafkasegt.1009879
A23	Aldemir Engin, R. (2023). Matematik öğretmeni adaylarının dijital oyun tasarlama deneyimleri, görüş ve değerlendirmeleri: Draw your game örneği. *ODU Sosyal Bilimler Araştırmaları Dergisi,* *13*(1), 89–114. https://doi.org/10.48146/odusobiad.1103234
A24	Avcu, S. (2023). Matematik öğretmen adaylarının Scratch ile tasarlanan dijital matematik oyunlarıyla ilgili farkındalıkları. *Van Yüzüncü Yıl Üniversitesi Eğitim Fakültesi Dergisi,* *20*(1), 126–149. https://doi.org/10.33711/yyuefd.1178451
A25	Poçan, S. (2023). Matematik eğitiminde dijital oyun tabanlı öğrenme üzerine bibliyometrik analiz. *İnönü Üniversitesi Eğitim Fakültesi Dergisi,* *24*(1), 648–669. https://doi.org/10.17679/inuefd.1215903
A26	Can, D. (2020). Supporting learning trajectories for the development of number concept: Digital games. *Journal of Theoretical Educational Science,* *13*(4), 663–684. https://doi.org/10.30831/akukeg.692165