International Journal of Serious Games

ISSN: 2384-8766
https://journal.seriousgamessociety.org/

Article

Serious games in science and mathematics education: a scoping umbrella review

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Keywords:

Educational games
Serious games
Science education
Mathematics education
Literature review
Umbrella review

Received: April 2024
Accepted: October 2024
Published: November 2024
DOI: 10.17083/ijsg.v11i4.765

Abstract

Many studies have reviewed the use of serious games as part of science and mathematics education. While previous reviews have focused on various educational levels and subjects, narrowing the scope to science and mathematics education provides targeted insights that can inform instructional strategies and curriculum development. In this study, we summarize 16 systematic reviews and meta-analyses with a total of 535 primary studies investigating the impacts of serious games in science and mathematics education. The papers analyzed reveal that serious games can motivate and engage students while helping improve their learning outcomes and cognitive skills. However, negative reports on the use of serious games in science and mathematics education, such as demotivation, anxiety, and limited effects on learning, are also observed. Overall, this study contributes to research on human–computer interaction by providing a comprehensive analysis of the impacts of serious games on students' moods and learning outcomes in science and mathematics education, highlighting the role of teachers and proposing future research directions for game-based learning.

1. Introduction

Many researchers have defined *serious games*, and a common aspect found across various definitions is that these games are designed to reach a certain goal rather than just provide entertainment [1, 24, 31, 59]. Serious games possess certain characteristics, such as being engaging and motivating, which make them efficient tools for implementation in various areas [10]. Within the realm of education, serious games have emerged as noteworthy tools that help facilitate the learning process in unique ways. These games not only improve soft skills but are also integrated into the teaching of core subjects, such as history [27, 66], science [17, 53, 65], and mathematics [7, 25, 62]. They enrich the educational experience, providing students with immersive and interactive learning opportunities across diverse academic disciplines. These learning opportunities are especially helpful in science and mathematics education, in which many students have difficulties comprehending related concepts [16]. Serious educational games can facilitate positive learning processes, as they help learners study a subject through an interactive, entertaining, and motivational pathway.

The utilization of serious games in the classroom has various effects on students' behaviors and moods. The incorporation of game mechanisms or gamification elements into these serious games can significantly boost students' motivation [46, 69] and confidence [14, 60] throughout the learning process. For example, one of the papers reviewed found that implementing serious games during the science course revision week had a transformative impact on low-performance students. It provided them with a fresh perspective on the subject and motivated active participation not only during the game-playing sessions but also afterward [34]. Additionally, engagement is a critical factor in facilitating the effective comprehension of new concepts, and serious games excel at inspiring students to interact with educational resources. Numerous studies have reported positive outcomes when using serious games, indicating that students find the learning experience enjoyable [4, 35, 68]. In fact, one of the primary objectives of integrating games into the teaching or learning process is to achieve positive changes in learning outcomes [71]. However, it is essential to acknowledge that in certain cases, serious educational games have negative impacts, causing anxiety [2], jealousy [22], and feelings of failure [5]. If students lack motivation to participate in classroom games, their overall engagement in the learning process is adversely affected. As such, the influence of serious educational games on students' behaviors remains a subject without a definitive conclusion [15]. Despite the promising benefits, the effectiveness of serious games, specifically in science and mathematics education, remains underexplored, particularly their impacts on students' cognitive and affective–motivational outcomes. This study addresses such a gap by conducting a scoping umbrella review of existing studies on the use of serious games in these subjects.

A learning outcome is prioritizing the essential knowledge and skills that students should acquire during the learning process [9]. According to the theoretical framework outlined by Battersby (1999), learning outcomes can be categorized into two main types: cognitive and affective–motivational. When mentioning *learning outcomes* in this study, we specifically address the cognitive aspect, encompassing conceptual or domain-specific knowledge, along with the capacity to remember, comprehend, and recall this acquired knowledge [50]. Researchers employ various methods to analyze the changes in learning outcomes when implementing serious educational games, such as conducting pretest–posttest designs in which they measure students' grades before and after playing the games [33, 39, 48, 54]. Interestingly, while a group of studies reported a significant improvement in students' grades because of educational games [18, 29, 43], another group of studies found no discernible effects on academic performance [20, 28]. It is crucial to recognize that each learner possesses unique characteristics and that their individual learning styles can differ significantly [32]. Therefore, instances in which students fail to achieve grade improvements through serious educational games may arise. However, such cases might be linked to specific game types or dynamics rather than to the overall efficacy of using games as learning tools [67]. As a result, reviewing the types of serious educational games that have been employed and gaining a comprehensive understanding of their impacts on learning outcomes are imperative.

Serious games have emerged as significant educational tools because they enhance student engagement and learning outcomes in various subjects, including science and mathematics [76]. Recent studies have highlighted the role of adaptive gamification in making learning personalized and effective [77]. For instance, adaptive gamification frameworks can dynamically adjust the difficulty level and provide real-time feedback, catering to individual student needs and learning paces. Zourmpakis et al. (2022) highlighted the importance of teacher training in the successful implementation of these technologies by ensuring that educators are well equipped to integrate gamified learning strategies into their classrooms [78]. Complementing these findings, those by Hamari et al. (2016) demonstrated that gamification can significantly increase student motivation and engagement, particularly when integrated with adaptive learning technologies [79]. Moreover, Deterding et al. (2011) discussed the broad implications of gamification in education, suggesting that well-designed game elements can foster critical thinking and problem-solving skills [80]. Collectively, these studies highlight the transformative potential of serious games and adaptive gamification in modern education, advocating for their broad adoption and integration into educational curricula.

The serious games used in the education field can be classified into two types: digital and nondigital [23]. Digital serious games are played using technological equipment, such as tablets and computers. One example of this type of game is Prodigy, which is an immersive and adaptive online math game in which players create their customizable avatars; to defeat monsters, players must answer math questions correctly. Nondigital serious games, also known as traditional games, are played using physical components, such as dice, boards, cards, and other tangible materials. An example of this type of game is Monopoly, in which players trade properties, aiming to bankrupt opponents. This game teaches soft and hard skills in financial literacy, negotiation skills, and basic economic concepts. In this scoping umbrella review, we considered both digital and nondigital serious games to include all types of educational games. In addition to game type, another important factor in the implementation of serious educational games is teachers' role, as teachers are among the key actors in the learning process [51].

The integration of serious games into educational curricula has gained significant attention because of their potential to enhance student engagement, motivation, and learning outcomes [81]. Despite the growing body of literature on the benefits of serious games in education, there remains a gap in understanding their specific impacts on science and mathematics education. This gap highlights the need for a comprehensive analysis of how serious games can be effectively implemented in these subjects to improve educational outcomes. The primary research problem addressed in the present study is the lack of a consolidated understanding of the impacts of serious games on student moods and learning outcomes in science and mathematics education. Additionally, there is a need to explore the role of teachers in the successful implementation of these educational tools. The objective of this study is to provide a comprehensive scoping umbrella review of existing research on serious games in these subjects by identifying both their positive and negative impacts and the critical role of educators.

Our research focused solely on serious games, in contrast to previous studies that encompassed both gamification and serious games in their reviews [40, 70]. Gamification applies game elements to nongame contexts to enhance engagement, whereas serious games are complete games designed with a specific educational or training purpose in mind [36]. To our knowledge, no recent umbrella review has delved into the use of serious games in science and mathematics education. This study presents a scoping umbrella review aimed at summarizing the evidence from existing reviews and meta-analyses concerning the use and impacts of serious games in science and mathematics education. The review highlights key findings, explores the role of teachers in the implementation of serious games, and identifies potential gaps in the literature that warrant further investigation in future research. Within this framework, this study intends to answer the following research questions (RQs):

- RQ1: What are the characteristics of review studies that investigate the impacts of educational games in science and mathematics education?
- RQ2: What is the overall impact of educational games on students' moods and learning outcomes in the domains of science and mathematics?
- RQ3: How does teachers' role influence the effectiveness of educational games in science and mathematics education?
- RQ4: What areas need further investigation to enhance our understanding of the impacts of educational games in science and mathematics education?

2. Methodology

Our aim was to provide an overview of published academic papers on the topic of using serious games in science and mathematics education and to report their positive and negative impacts on students' moods and learning outcomes. We also analyzed teachers' role in serious game implementation and the research gap in this field. For this purpose, we conducted a scoping umbrella review in which we reviewed previous papers on this topic. To conduct the review, we followed five steps: identifying the research questions and objectives, conducting a preliminary search, screening and selecting studies, charting the data, and reporting the results [45, 63]. The main reason why we decided to conduct a scoping umbrella review was that it evaluates a broad range of existing evidence by incorporating multiple systematic reviews or meta-analyses. We started our research by identifying the databases that we used to search for the papers, as well as setting the inclusion and exclusion criteria. Fig. 1 presents our review process based on the PRISMA statement [41].

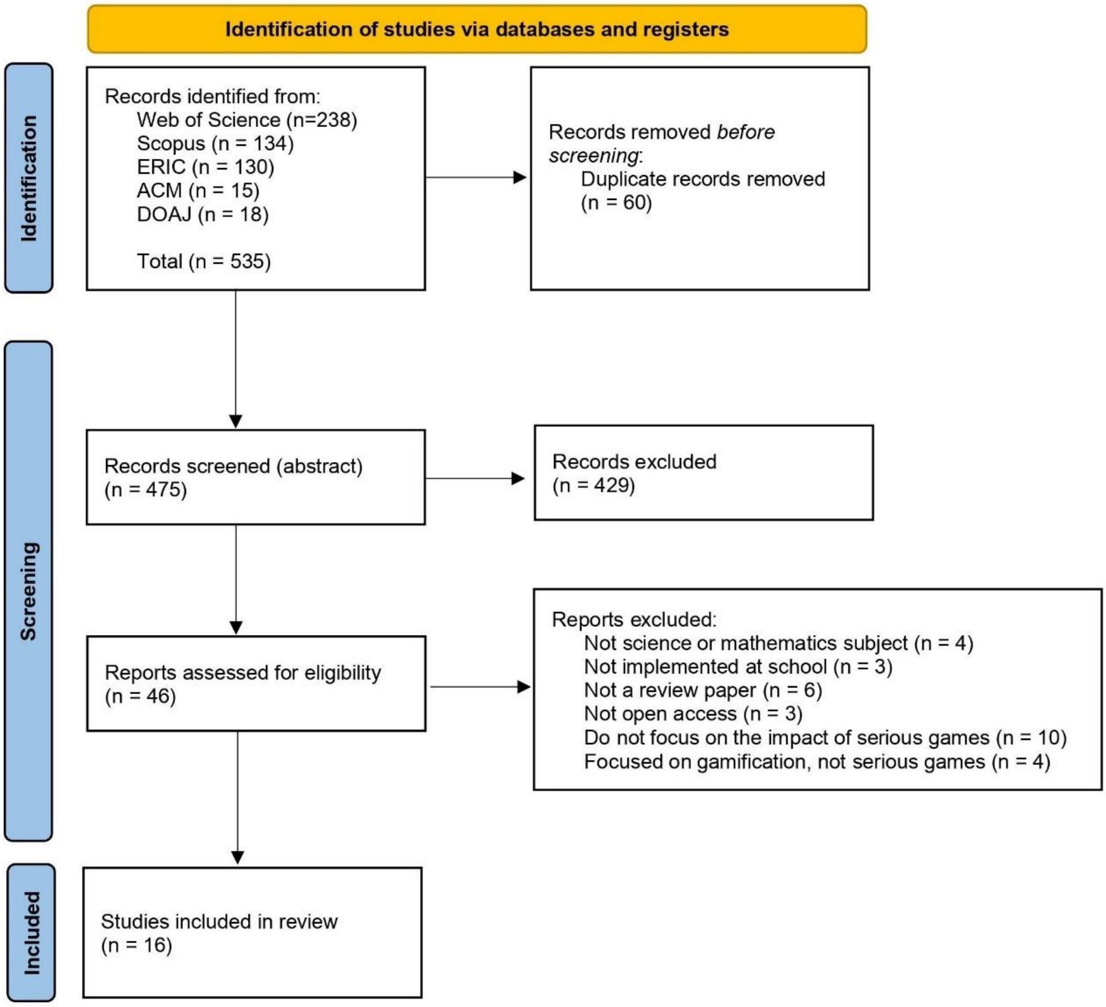

Figure 1. PRISMA flowchart of the reviews included in this scoping umbrella review.

2.1 Conducting a preliminary search

We used the Scopus, Education Resources Information Center, Association for Computing Machinery Digital Library, Directory of Open Access Journals, and Web of Science databases to collect publications that reviewed the use of serious games in science and mathematics education. The search was conducted using the following string: ("serious game*" OR "educational game*") AND ("review" OR "meta-analysis") AND ("school" OR "elementary" OR "primary" OR "secondary"). If needed, the string was adapted to meet the specific requirements of various online databases. While searching, we included papers that were published in English between January 1, 2019, and July 1, 2023. We decided to search papers broadly so as not to exclude any papers that may be subject to inclusion while conducting the review.

2.2 Screening and selecting studies

We added the search results to a Google Sheets document, which served as a masterfile; this allowed all authors to communicate and collaborate simultaneously. Two reviewers (AK and MS) screened the abstracts and titles of the first 100 papers and marked in the masterfile whether the paper should be included. This helped calibrate the review process and resolve any ambiguities in the criteria. Once a consistent review process was established, one author (AK) continued the review to maintain efficiency while still following the established criteria. Throughout the process, any uncertainties or ambiguities encountered by the reviewer (AK) were discussed and resolved collaboratively with the other authors to maintain consistency in the review. If the author did not decide on the inclusion status of a paper, they then noted that this paper should be discussed with the other researchers. In this instance, the authors read the full body of the paper and made their decisions accordingly.

As the next step, we screened the selected papers from the initial screening process. In the review process, we excluded papers that did not meet our criteria. The exclusion criteria were as follows:

- The paper did not review the implementation of serious games at school. We also excluded papers that did not focus on the school level (primary, elementary, and secondary) (e.g., [21]).
- The paper did not focus on the implementation of serious games in science and mathematics education. The present study exclusively concentrated on the application of serious games in science and mathematics education. In our research, the term “science” refers to biology, physics, and chemistry subjects, while “mathematics” includes algebra and geometry. Review papers that did not discuss either science or mathematics education that uses serious games were omitted from the analysis (e.g., [47]).
- The papers were not review papers. During the search process, we utilized the “review” and “meta-analysis” parameters to identify review papers. However, upon reviewing the papers, we noticed that some did not meet the criteria for being review papers and were subsequently excluded (e.g., [58]).
- The context of the paper was not the analysis of the impacts of serious games, and it focused instead on other perspectives of serious games, such as gamification elements or the design framework of serious games. If a paper did not report any results on the effects of using serious games in science or mathematics education, then this paper was excluded (e.g., [49]).
- The paper focused on gamification. Gamification adds game elements to nongame contexts to enhance motivation and engagement, whereas serious games are fully fledged games [6]. Thus, we excluded records that investigated gamification and not serious games (e.g., [11]).

All exclusion criteria, except the third one, were defined before starting the research. In essence, a paper was considered eligible for inclusion if it conducted a literature review, meaning that it thoroughly examined a topic and went beyond merely presenting related work. Following the final screening process, 16 papers eligible for inclusion in this research were identified.

2.3 Charting the data

We utilized inductive open coding using reflexive thematic analysis to categorize the studies. This specific method was chosen because of its flexibility and iterative nature, enabling a dynamic and adaptable approach [12, 13]. We followed five steps: identifying the research questions and objectives, conducting a preliminary search, screening and selecting studies, charting the data, and reporting the results [45, 63]. These steps are described in detail in the following sections (2.1–3). In the initial stage of the research, based on iterative discussions, an initial coding tree was established, and certain codes were predefined to collect background information about each paper, including the publication year, inclusion year of the papers reviewed, review type, number of papers reviewed, and methodology employed. Additionally, three codes were defined based on the research questions, covering the school level, type of game, and the subject in which serious games were implemented. As the authors reviewed the papers, they identified the common positive and negative impacts of serious games, which were subsequently added as codes. For positive impact, codes such as motivation, enjoyment, positive learning outcomes, cognitive skill, behavior change, and engagement were included, whereas negative impact codes included low engagement, less motivation, anxiety, jealousy, and no or minimal change in learning outcomes. Papers reporting these factors were marked with "1," whereas those not mentioning them received "0." Moreover, any other positive or negative factors mentioned were recorded in the masterfile as notes for consideration. Finally, after the papers were reviewed, a code regarding the significance of teachers in the application of serious games in science and mathematics education was added. If uncertainties emerged, they were discussed thoroughly by all authors during the entire process. We then conducted the final session, in which we discussed the final set of codes with all authors.

2.4 Assessing methodological quality

To evaluate the methodological quality of this scoping umbrella review, we used a systematic appraisal tool, Assessing the Methodological Quality of Systematic Reviews (AMSTAR), which consists of 11 items [55]. These items evaluate a specific aspect of the review methodology. We scored each item in the checklist as "met," "not met," "unclear," or "not applicable." Two reviewers (AK and MS) independently conducted the appraisal. Moreover, according to AMSTAR, this scoping umbrella review provides a clear research aim and follows a scoping umbrella review methodology using predefined inclusion and exclusion criteria. The AMSTAR checklist can be found in Appendix I.

3. Results

This section provides an overview of the analysis results. To begin, we present the general characteristics of the papers reviewed. Subsequently, we explore the main findings concerning the positive and negative impacts of serious games on students' moods and learning outcomes. We also discuss the role of teachers in the implementation of serious games in science and mathematics education, along with the future research directions proposed by the studies reviewed.

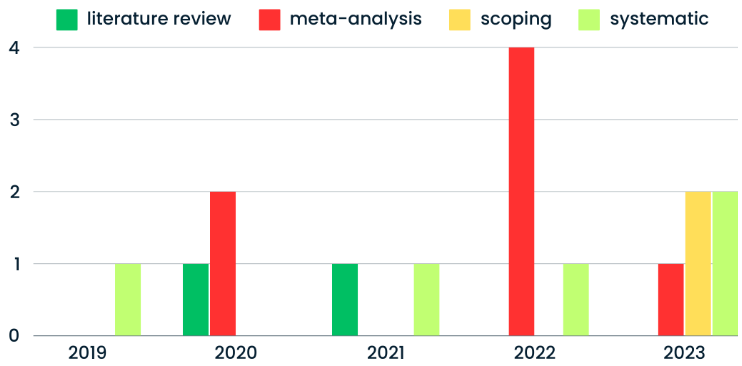

Figure 2. Review types and their distribution over the years.

3.1 Study selection and characteristics of the reviews included

The initial research identified 535 papers from five databases. After removing duplicates (n = 60) and excluding records (n = 429) after the abstract screening, we obtained 46 records for eligibility assessment (Fig. 1). From these records, 16 were included. Moreover, the number of reviews has been increasing since 2019; meta-analyses (n = 7) and systematic literature reviews (n = 5) were the most common types that focused on the impacts of serious games in science and mathematics education. Table 2 depicts the main characteristics of these papers, such as the number of papers included in the review studies, the inclusion period, the education level in which it was implemented, and the main types of games. While the average number of papers reviewed was around 53, the most common trend was the inclusion of studies that focused on the primary, elementary, and secondary education levels altogether. The common game types were board and quest games.

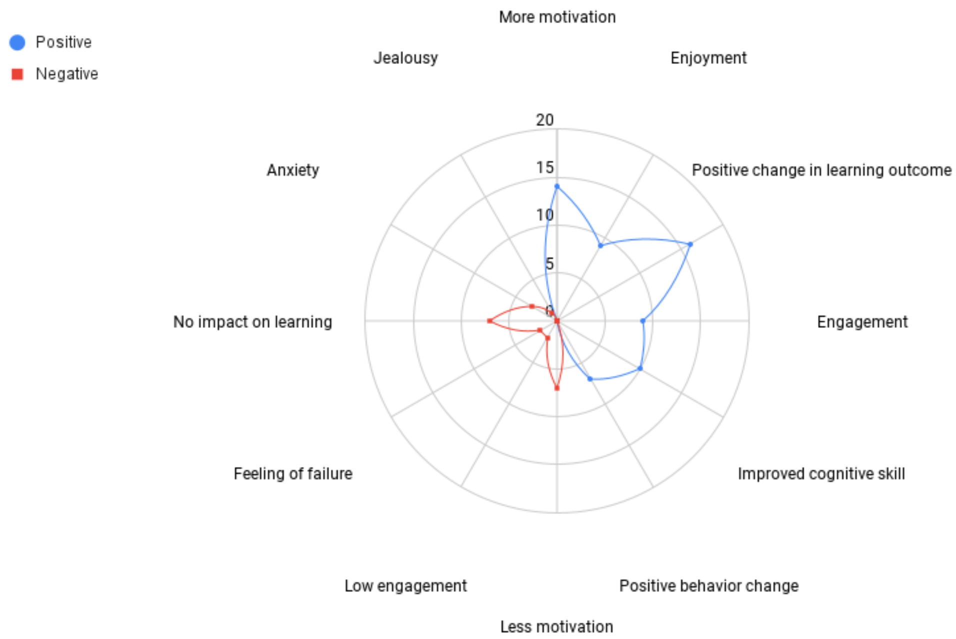

Figure 3. Overview of how many of the 16 reviews reported different positive and negative impacts of using educational games.

3.2 Impacts of serious games on students' moods and learning outcomes in science and mathematics

While most research papers highlight the positive impacts of using serious games in science and mathematics education, a subset of studies also report some negative effects on students' moods and learning outcomes. In Fig. 3, the primary positive and negative impacts of employing serious games can be observed. Each dot on the radar chart represents the number of studies that reported this effect in their respective research. On the positive side, serious games were found to be motivating, enjoyable, and effective in increasing learning outcomes (Table 1). They also improved student engagement and cognitive skills and positively influenced behavior. In addition, the use of escape rooms as serious games allowed students to apply their skills and knowledge in complex contexts, although this slightly affected learning outcomes. Another common positive impact was an increase in academic self-confidence, which made the students assured in solving mathematics and science problems.

Table 1. Impacts of Serious Games on Students' Moods and Learning Outcomes

Impact Category	Papers
Motivating	[3, 4, 14, 19, 25, 26, 30, 37, 38, 52, 57, 60, 61, 67]
Enjoyable	[3, 14, 25, 30, 37, 52, 60, 61]
Effective in increasing learning outcomes	[3, 4, 8, 14, 19, 25, 26, 30, 37, 38, 52, 53, 57, 60, 61, 67]
Improved student engagement	[3, 14, 19, 26, 30, 52, 57, 60, 61]
Enhanced cognitive skills	[3, 4, 14, 19, 26, 30, 52, 57, 60, 67]
Positive behavior influence	[4, 19, 30, 37, 52, 57, 60]
Increased academic self-confidence	[14, 37, 60]
Demotivating	[3, 4, 8, 19, 26, 30, 60]
Decreased engagement and feelings of failure	[3, 60]
No significant impacts on learning	[4, 8, 14, 19, 30, 60, 61]
Anxiety	[3, 37, 60]
Jealousy	[60]
Negative emotions, such as nervousness	[19]
Negative impacts on overall class performance	[60]

On the other hand, some negative effects of serious games were observed. They were found to demotivate students, decrease engagement, and lead to feelings of failure. In some cases, serious games did not have significant impacts on learning, and they were associated with feelings of anxiety and jealousy. There were instances in which utilizing serious games in the classroom led to negative emotions, such as nervousness, because of unfamiliar settings, and the improvements in emotional intelligence did not persist at a three-month follow-up. Overall, it was noted that if serious games are not thoughtfully designed, implemented, and well integrated with the learning content, they can negatively affect students. Additionally, Talan et al. (2020) reported that serious games may have negative impacts on overall class performance, as they can lead to addiction, occur in noisy environments, and require a long time to set up.

Table 2. Review Studies on the Impacts of Serious Games in Science and Mathematics Education

Study	Inclusion Period	Number of Papers Reviewed	School Level	Types of Games
Hussein et al. (2019) [30]	2006–2017	23	elementary	role playing, board, simulation, strategy

Taraldsen et al. (2020) [61]	2017–2020	70	primary, secondary	escape, board, computer
Riopel et al. (2020) [61]	All time	79	primary, elementary, secondary	digital and nondigital games, escape
Talan et al. (2020) [60]	2004–2019	154	primary, elementary, secondary	digital game, simulation
Lathwesen and Belova (2021) [37]	2007–2021	93	primary, elementary, secondary	AR game, immersive games, tutorial games, board games
Fadda et al. (2022) [25]	2000–2019	20	primary, elementary, secondary	video game, card, board, computer
Ređep and Hajdin (2021) [52]	2010–2020	52	primary, elementary, secondary	Virtual Reality (VR), Augmented Reality (AR)
Wang et al. (2022) [67]	2010–2020	33	primary, elementary, secondary	video
Lei et al. (2022) [38]	2009−2021	41	primary, elementary, secondary	card, memory, sound, matching, video
Arztmann et al. (2022) [4]	2008−2020	39	primary, elementary	N/A
Byusa et al. (2022) [14]	2000−2021	16	elementary, secondary	tabletop, board, quest, card
Barz et al. (2020) [8]	2015−2020	36	primary, secondary	N/A
Cole et al. (2023) [19]	2010−2020	85	elementary, secondary	N/A
Gallud et al. (2023) [26]	2009−2019	18	primary, secondary	N/A
Arosquipa Lopez et al. (2023) [3]	2012−2022	54	primary, elementary	N/A
Sousa et al. (2023) [57]	2012−2022	45	elementary, secondary	N/A

3.3 The role of teachers

Six of the papers reviewed [3, 8, 14, 19, 25, 37] highlighted the crucial role of teachers in utilizing serious games effectively in science or mathematics classes. They reported that educators can actively engage as game masters, verifying answers and providing specific instructions during gameplay, as well as positively influencing students' engagement with the games [37]. However, when teachers lack the necessary skills, experience, or knowledge related to serious games, their implementation in the classroom can lead to student discouragement and fatigue [3]. Moreover, some teachers express interest in using serious games but may be hesitant because of concerns about their own game literacy and proficiency [7]. In summary, while the literature underscores the important role of teachers in serious game implementation, it is equally essential for them to possess the prior knowledge and practical skills to ensure successful integration.

3.4 Proposed future research directions

Studies also reported potential future research directions in the review of papers focusing on the impacts of serious games on science and mathematics education. The proposed future work directions can be summarized into four categories: effects of serious games on learning and instruction, game-based learning design and mechanics, educational escape games and didactic tools, and emerging technologies and game applications. First, from the perspective of the effects of serious games on learning and instruction, Hussein et al. (2019) [30] proposed exploring how different learning dynamics affect science learning and examining the influence of serious games on creativity, complex problem-solving abilities, and critical thinking skills. Talan et al. (2020) [60] called for empirical studies to assess the impact of nondigital games on learning components and compared their efficiency with that of digital games for instructional purposes. Additionally, Fadda et al. (2022) [25] advocated conducting research with large sample sizes to gain in-depth insights into the effects of serious games on student learning outcomes. Second, future research can focus on enhancing game-based learning design, and mechanics and exploring their effects on science, technology, engineering and mathematics (STEM) education and learner interest [53, 67]. Subsequently, while Taraldsen et al. (2020) [61] proposed researching the experiences and beliefs of teachers regarding the use of escape rooms in 21st-century education, Lathwesen and Belova (2021) [37] suggested investigating the effects of educational escape games on motivation, collaboration, creativity, problem solving, and knowledge acquisition. Lastly, another future research direction was the use of augmented reality with game elements in primary and/or secondary education [8, 52].

4. Discussion

This scoping umbrella review focused on the impacts of serious games in science and mathematics education, and the findings can be summarized under three categories: the impacts of serious games on students' moods and learning outcomes, teachers' role in the implementation of serious games, and proposed future research directions by the studies reviewed. Most of the papers reported that using serious games can positively affect students' attitudes toward the learning process and improve students' learning outcomes. Nevertheless, in some cases, using serious games as part of science and mathematics education leads to negative results. Additionally, there is a concern about *edutainment*, in which the entertainment value of a game may overshadow educational content [73]. This can result in students enjoying the game without necessarily achieving the intended learning outcomes. Therefore, striking a balance between educational rigor and entertainment is essential to ensure that learning objectives are achieved. Previous studies have also mentioned that serious games do not affect all students equally. For example, compared with students with lower digital literacy, students with higher digital literacy are more prone to adopting serious games, as they are more familiar with similar environments [34]. From another perspective, the characteristics of students are also among the key factors that determine how effectively serious games engage them. For instance, Smiderle et al. (2019) [56] reported that introverted students using a gamified platform demonstrated higher engagement levels, submitted a greater number of correct solutions, and achieved higher rankings and visualizations of their progress through points and badges. By contrast, extroverted students in the same gamified group exhibited different patterns in their usage and engagement with the system. Thus, as expected, serious games affect students differently. The impacts of serious games may also be moderated by contextual factors, such as socioeconomic status and access to technology [74]. Students from under-resourced communities might experience different levels of benefit from serious games because of disparities in access to supporting technologies and varying levels of prior digital literacy.

This scoping umbrella review reveals a crucial finding regarding the significance of teachers' role in implementing serious games within science and mathematics education. Teachers play a pivotal role in the learning process, and their approach to any teaching method directly influences its outcomes. Teachers' attitudes toward technology can significantly influence the effectiveness of serious games. Teachers who are resistant to integrating technology into their teaching may inadvertently undermine the potential benefits of serious games [75]. Thus, addressing these attitudes through targeted professional development that emphasizes the pedagogical value of game-based learning is important. This review has highlighted that motivated and knowledgeable teachers who understand how serious games in the classroom can be effectively integrated have a positive impact on students' learning outcomes and moods. Molin (2017) [42] and Tzuo et al. (2012) [64] also emphasized the importance of teachers in game-based learning, underscoring the need for teachers to possess sufficient game literacy to provide appropriate guidance during gameplay. This finding underscores the significance of teachers' professional development in the successful integration of serious games, ultimately enhancing the learning experience for students in science and mathematics education.

The third finding concerns the potential future research directions reported by the studies. As we found in our scoping review, other studies also mentioned the importance of conducting research within the scope of serious games and emerging technologies, such as the application of narrative choice and fantasy customization in augmented reality serious games [72]. Another potential future research direction could focus on investigating the effects of serious games on learning and instruction from different perspectives. Previous research has also mentioned that analyzing students' learning by deploying different techniques, such as clustering students' profiles based on various variables (e.g., units and the types of errors that students make while playing games), can give a good understanding of learning outcomes [44].

The reliability of the study outcomes is supported by the comprehensive methodology used, which reviews findings from 16 systematic reviews and meta-analyses, covering 535 primary studies. This extensive dataset ensures consistency and reliability by providing a broad overview of the existing evidence. The methodology is transparent because it details the databases searched, the search strings used, and the inclusion/exclusion criteria, allowing for reproducibility and supporting reliability. The collaborative review process, which involved multiple authors who screened and selected studies while resolving ambiguities, further enhances the reliability of the data collection process. Moreover, internal validity is supported by using established coding methods, such as inductive open coding and reflexive thematic analysis, which provide a solid framework for data categorization and analysis. The application of the AMSTAR checklist to assess the methodological quality of the reviews further strengthens internal validity. External validity is ensured by including studies from various educational contexts (primary, elementary, and secondary education) and different types of serious games (digital and nondigital), although the focus on science and mathematics education may limit generalizability to these specific subjects. Construct validity is maintained through clear definitions of key concepts, such as serious games, learning outcomes (cognitive and affective–motivational), and the role of teachers, ensuring accurate representation and measurement.

Future research should consider conducting scoping umbrella reviews specific to subjects or school levels to understand the impacts of serious games in different educational contexts. Focusing on particular subjects (e.g., science and mathematics) or education levels (e.g., primary, elementary, and secondary) will allow for an in-depth understanding of how serious games affect learning outcomes in each setting. Additionally, investigating how different subject teachers adopt and implement serious games in their classrooms is crucial.

Each subject comes with its unique challenges and learning objectives, and teachers may have varying levels of familiarity and comfort with incorporating serious games as educational tools. Understanding teachers' experiences and practices will provide insights into the factors that influence successful integration and inform targeted support and professional development initiatives to optimize the use of serious games in subject-specific instruction. Future research should also investigate the potential of serious games to support personalized learning. With advancements in artificial intelligence, serious games could be designed to adapt to students' individual learning needs by providing related challenges and support. This personalization could enhance the effectiveness of serious games by ensuring that all students, regardless of their starting points, can benefit. Additionally, ethical considerations related to data privacy and the use of student data in game-based learning environments must be explored. As serious games often collect data on student performance, establishing clear guidelines on how these data are used and protected is essential to ensure that student privacy is not compromised.

The limitations of this review include the exclusion of studies published before 2019, which might have provided valuable insights into the historical development of serious games in education. The exclusion criteria omitted studies focusing on gamification, nonschool settings, or subjects other than science and mathematics, which might overlook valuable insights from broad educational contexts. The variability in methodologies among the reviews and meta-analyses included can lead to inconsistent findings, affecting comparability. Despite efforts to include gray literature, there is still a risk of publication bias in which studies with positive outcomes are more likely to be published than those with null or negative results. Additionally, the study highlights the critical role of teachers in implementing serious games, but it acknowledges that not all teachers possess the necessary skills or experience, which can affect the effectiveness of serious games.

5. Conclusion

This scoping umbrella review aimed to provide an analysis of the use of serious games in science and mathematics education by focusing on their impacts on students' moods and learning outcomes. In addressing RQ1 (What are the characteristics of review studies that investigate the impacts of educational games in science and mathematics education?), we found that most of the studies reviewed focused on the primary, elementary, and secondary education levels. For RQ2 (What is the overall impact of educational games on students' moods and learning outcomes in the domains of science and mathematics?), our findings demonstrated that serious games generally enhance motivation, enjoyment, cognitive skills, and academic self-confidence, although some negative effects, such as demotivation, anxiety, and limited learning impact, were also reported. In response to RQ3 (How does teachers' role influence the effectiveness of educational games in science and mathematics education?), we emphasized the critical role of teachers in the effective implementation of serious games by highlighting the necessity for teachers' professional development to ensure successful integration. Addressing RQ4 (What areas need further investigation to enhance our understanding of the impacts of educational games in science and mathematics education?), we identified several areas for future research, including the need for empirical studies with large sample sizes, the exploration of different game dynamics, and the integration of emerging technologies. Overall, this systematic review contributes to the field of human–computer interaction by offering insights into the benefits and challenges of using serious games in education; it also suggests directions for future research to optimize the use of such games in science and mathematics education.

Additionally, serious games provide an opportunity to bridge the gap between theoretical knowledge and practical application by providing students with hands-on experience in a safe and controlled setting. The adaptive nature of these games ensures personalized learning experiences by allowing each student to progress at their own pace and receive targeted support, where needed. This not only makes education inclusive and effective but also fosters a lifelong love for learning by creating a dynamic and interactive classroom environment.

In conclusion, while this study presents reliable and valid outcomes, considering its limitations is also important. Nonetheless, the potential benefits of serious games in science and mathematics education are substantial, offering promising directions for future research and practice. This study helps us understand the current landscape of serious games and provides valuable insights that can guide practitioners and game designers in the development and application of serious games. By highlighting both the positive impacts and challenges involved, this review supports the creation of effective and engaging educational tools, ultimately enhancing students' learning experiences.

Acknowledgments

All records assessed for eligibility in this umbrella review are available in the open-access repository at https://zenodo.org/record/8208951. The work was supported by the Academy of Finland (grant no. 356314).

Conflicts of interest

The authors have no conflicts of interest to declare.

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Appendix

A. AMSTAR Evaluation

1. Was an "a priori" design provided? – Met
   Explanation: The authors clearly stated their research aims and objectives before conducting the scoping umbrella review of previous review papers on the topic of using serious games in science and mathematics education.
2. Was there duplicate study selection and data extraction? – Met
   Explanation: Two reviewers (AK and MS) conducted the initial screening of abstracts and titles for the first 100 papers, and any discrepancies were resolved through discussion. The subsequent screening was done by one author (AK). Moreover, after all papers were screened, duplicates were removed from the masterfile to which review papers were added.

3. Was a comprehensive literature search performed? – Met
   Explanation: The review conducted a literature search in multiple databases (Scopus, ERIC, ACM Digital Library, DOAJ, and WoS) using a predefined search string.
4. Was the status of publication (i.e., gray literature) used as an inclusion criterion? – Met
   Explanation: The review included papers published in English between January 1, 2019, and July 1, 2023, and considered gray literature as well.
5. Was a list of studies (included and excluded) provided? – Met
   Explanation: The review provides information on the number of papers included and excluded during the screening process. The exclusion criteria were clearly defined.
6. Were the characteristics of the included studies provided? – Met
   Explanation: The review describes the characteristics of the included studies, such as publication year, review type, number of papers reviewed, and methodology employed.
7. Was the scientific quality of the included studies assessed and documented? – Met
   Explanation: To avoid any publication bias, we included all screened review or meta-analysis studies without depending on their scientific quality.
8. Was the scientific quality of the included studies used appropriately in formulating conclusions? – Met
   Explanation: We exclusively included papers that reported the impacts of serious games on students' moods or learning outcomes. If a paper did not mention any impact, it was excluded from the analysis.
9. Were the methods used to combine the findings of the studies appropriate? – Not applicable
   Explanation: Quantitative measures of homogeneity were not applicable in this scoping umbrella review; however, by summarizing the similarities and differences among the included studies, we were able to address this issue.
10. Was the likelihood of publication bias assessed? – Met
    Explanation: We screened all types of publications, ensuring a comprehensive and unbiased representation of the evidence.
11. Was the conflict of interest stated? – Met
    Explanation: There were no conflicts of interest disclosed by the authors.