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REVIEW AND SYNTHESIS

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A systematic review of paper-based and digital board games for collaborative science learning

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Abstract

This study reviews the literature on board games for collaborative learning in science education, analysing 76 articles from 2000 to 2024. It examines research methodologies, data collection tools, sample sizes, and data analysis methods, focusing on subject areas and types of board games used. Key findings reveal a predominance of physical (paper-based) board games. Research methodologies were primarily quantitative, with descriptive analysis being the most common approach, typically employing varied sample sizes (median 48.5 participants). Evidence suggests that board games can enhance scientific knowledge acquisition, improve student engagement, and foster collaborative skills. However, the review identifies critical limitations in the existing literature, including a prevalence of small sample sizes, a lack of long-term effectiveness studies, and insufficient focus on specific game mechanisms. Future research should prioritise investigating game mechanisms, explicitly measuring collaborative learning outcomes, improving methodological rigour, and assessing long-term impacts on knowledge retention.

KEYWORDS

board games, collaborative learning, science education

INTRODUCTION

Board games have emerged as a promising tool for enhancing science education, transcending their traditional role as purely recreational activities (Kuo & Hsu, 2020) and fostering a more engaging and interactive learning experience in both physical and digital formats

Context and implications

Rationale for this study: This systematic review addresses a gap by synthesising empirical evidence on board games for collaborative learning in science education, providing a comprehensive overview of existing research.

Why the new findings matter: Our findings quantify board games' positive impacts on science knowledge, engagement, and collaborative skills, while identifying methodological gaps and crucial future research directions.

Implications for educational institutions, policymakers, educators and learners: This review highlights effective practices for integrating board games into science education, guiding the creation of more engaging and impactful collaborative learning experiences. For researchers: It identifies critical gaps in the literature, emphasising the need for studies on specific game mechanisms, long-term effectiveness, enhanced methodological rigour (e.g. control groups, inferential statistics), and exploration across diverse populations and digital technologies. This provides a roadmap for future investigations to deepen our understanding and optimise the integration of board games.

(Lin & Hou, 2024a; Othman & Sim, 2024; Surapaneni, 2024). Their capacity to seamlessly integrate learning elements with the inherent fun and competitive nature of games promotes deeper engagement, making them ideal for enhancing science education (Othman & Sim, 2024).

One compelling reason to utilise board games in science education is their potential to foster collaborative learning, a fundamental skill for scientific literacy (Teixeira & Vasconcelos, 2024). Science education inherently benefits from teamwork, as collaborative inquiry, problem-solving, and effective communication are essential components of scientific literacy (Cheng et al., 2024). Board games often necessitate players to work together, negotiate strategies, and share knowledge to achieve a common goal, suggesting they could be valuable tools for cultivating critical science learning skills.

While studies across various subjects demonstrate the potential of board games to enhance learning (Arboleya-García & Miralles, 2022; Chang et al., 2022), their effectiveness in fostering both collaborative learning and supporting science learning outcomes remains an area of active research (Kalogiannakis et al., 2021; Kuo & Hsu, 2020; Lin & Hou, 2024a; Othman & Sim, 2024). This has led to increased research focused on examining the effectiveness of board games in this domain (Küçükşen Öner et al., 2024; Othman & Sim, 2024), particularly digital game-based learning (Khattib & Alt, 2024; Lin & Hou, 2024a). Some studies have shown positive outcomes, such as improved learning and positive attitudes towards collaboration (Surapaneni, 2024). However, others have indicated that collaborative groups might not always achieve optimal learning results despite increased motivation (Lin & Hou, 2024a). This ambiguity underscores the need for further investigation into how board game design elements and implementation strategies can be optimised to maximise the benefits of collaborative learning outcomes in classrooms.

Collaborative learning environments are increasingly valued in science classrooms, promoting student interaction, shared discoveries, and active knowledge construction (Long et al., 2024; Yan et al., 2024). Board games, with their emphasis on communication and

collaboration, have the potential to address these needs and contribute to the development of scientific literacy (Barrett & Westlin, 2021).

This systematic literature review aims to address this critical gap by investigating the effectiveness of board games in science education. For the purposes of this review, 'science education' serves as a broad umbrella term encompassing general or interdisciplinary science contexts, as well as specific core scientific disciplines such as Biology, Chemistry and Physics. We also include studies situated within STEM (Science, Technology, Engineering, and Mathematics) education, provided their primary pedagogical focus or investigated learning outcomes are clearly related to the scientific component or scientific inquiry. This review will identify potential areas for future investigation by critically examining existing research methodologies, data collection tools, and sample sizes in past studies. Additionally, exploring the types of board games used and their effectiveness in different science subject areas will provide valuable insights for researchers and educators seeking to integrate board games into science curricula across diverse educational settings.

This study aims to answer the following overarching research questions:

RQ1. What are the characteristics of the studies investigating the effectiveness of board games in science education?

RQ1a. What research methodologies are most commonly employed in studies exploring the use of board games for collaborative learning in science education?

RQ1b. What data collection tools are frequently used in these studies?

RQ1c. What are the typical sample sizes employed in research on board games and collaborative learning within science education?

RQ1d. What data analysis methods are predominantly utilised in this research area?

RQ2. What are the main subject areas and specific topics within science education where board games are used for collaborative learning, and what impacts do they have?

RQ2a. What are the main subject areas where board games are implemented for collaborative learning in science education?

RQ2b. What specific science topics are addressed in these studies utilising board games for collaborative learning?

RQ2c. What types of board games are used in research on board games and collaborative learning in science education?

RQ2d. What are the impacts of board games in collaborative science education?

The following section outlines our methodology for conducting the literature review. We subsequently present our results in response to the research questions. Next, a discussion section addresses our two overarching research questions. Finally, we conclude our review and provide suggestions for future works.

REVIEW OF LITERATURE

Science education

Effective science education equips individuals with the knowledge, skills and attitudes to understand and engage with the natural world (Rosenberg et al., 2022). It emphasises inquiry-based learning, where students actively investigate phenomena, formulate hypotheses, collect and analyse data, and draw evidence-based conclusions. This approach fosters scientific literacy, enabling individuals to understand scientific concepts, apply scientific knowledge to real-world problems, and engage in informed discussions about science-related issues. Furthermore, developing 21st-century skills such as critical thinking, problem-solving, creativity, and collaboration is crucial for success in science and life.

Teachers play a pivotal role in creating engaging and effective learning experiences. They guide students through scientific investigations, facilitate discussions, and provide support in developing conceptual understanding (Haridza & Ding, 2024; Sutiani, 2021). Effective communication between teachers and students is essential for fostering a dynamic learning environment. Teachers contribute scientific knowledge to the classroom, supporting students in developing conceptual understanding through investigations and evidence-based reasoning (Antonio & Prudente, 2021). Students, in turn, actively engage with scientific skills and strive to construct their understanding of scientific concepts. Additionally, students must articulate scientific ideas using the language of science within the science classroom (Barrett & Westlin, 2021).

Board games, with their interactive and engaging nature, have the potential to align with these key principles of science education. By incorporating game-based learning, educators can create dynamic learning environments that foster active engagement, collaborative problem-solving, and the development of essential 21st-century skills.

Collaborative learning

Collaborative learning, a pedagogical approach that fosters student interaction and active knowledge construction, has gained prominence in contemporary educational settings (Tsai et al., 2021). It involves small groups of students working together to achieve common learning goals (Vuorenmaa et al., 2024; Zheng et al., 2023), particularly through discovery-based methods (Saif et al., 2021). Teachers play a crucial role in creating activities that facilitate learning experiences and promote effective collaboration among students (Dragnić-Cindrić et al., 2024; Li et al., 2024).

Technological advancements have significantly expanded the possibilities for collaborative learning, especially within digital environments. Electronic devices and wireless communication technologies have become integral in facilitating student engagement and fostering collaboration within these processes (Tlili et al., 2022; Yoon & Khambari, 2022), enabling students to share resources, communicate, and collaborate on projects in real-time, fostering engagement and knowledge acquisition. This technological integration is particularly relevant to game-based learning, where digital board games, with their interactive and engaging mechanics, offer innovative opportunities for collaborative problem-solving, teamwork, and critical thinking (Asakle & Barak, 2022; Yu et al., 2022).

Board games and collaborative learning in science education

Board games are typically defined as tabletop games that involve playing pieces, cards, and often dice on a designated surface, governed by a set of rules (Gennari et al., 2019a). Unlike video games, board games typically involve physical components and require face-to-face

interaction, although digital adaptations exist that retain the core board-game mechanics (as further defined in Section 3.2). While board games have traditionally served entertainment purposes, their interactive and engaging nature makes them particularly attractive for educational settings, including science education (Musick et al., 2021; Othman & Sim, 2024). For this review, we focus specifically on board games utilised for educational purposes.

Well-designed board games can foster a collaborative learning process by promoting teamwork, communication, and information-sharing among players (Othman & Sim, 2024; Tyo & McCurry, 2021). Board games encourage students to actively participate, share ideas, and construct knowledge through collaborative inquiry. Studies have shown that board games can enhance investigative and decision-making skills (Lin & Hou, 2024b; Tsai et al., 2021), which is crucial for scientific inquiry. Furthermore, board games can encourage healthy competition, fostering a positive attitude towards learning from both success and failure (Lala & Mentz, 2022).

Beyond their mere presence as educational tools, the specific mechanisms embedded within board games are considered crucial drivers of learning. Game mechanisms refer to the rules and systems that govern player interaction and progression, such as cooperative play, competitive scoring, resource management, negotiation, role-playing, and problem-solving challenges (e.g. Deterding et al., 2011; Huizinga, 1971). These mechanisms directly influence the cognitive processes engaged, the nature of social interaction, and the types of skills developed during gameplay. For instance, cooperative mechanisms can explicitly promote teamwork and shared decision-making, while strategic resource management can enhance critical thinking and planning. Understanding these underlying mechanisms is crucial for designing effective educational games and accurately interpreting their impact on learning outcomes.

This integration of collaborative learning and game mechanics aligns perfectly with the growing emphasis on student-centred learning in science education (Othman & Sim, 2024). Collaborative learning environments in science classrooms encourage students to collaborate, share discoveries, and construct knowledge through active participation (Saif et al., 2021; Yan et al., 2024). By providing a structured yet engaging platform for collaboration, board games can effectively support the development of 21st-century skills, such as critical thinking, problem-solving, and communication, within the context of science education.

However, it is essential to acknowledge that board games may have limitations in science education. The content covered by a single game may be restricted, and utilising board games effectively in large classrooms can pose challenges. Furthermore, different types of board games (cooperative vs. competitive) can be utilised to encourage collaborative learning. Subsequent research can investigate the efficiency of various board game designs in fostering specific science learning objectives within collaborative learning environments.

METHODS

This systematic literature review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021) to ensure a rigorous and transparent process. Our methodology involved five key stages: defining research questions, establishing eligibility criteria, developing a search strategy, selecting studies, and extracting and coding data.

Search strategy

We conducted a comprehensive search across five electronic databases: Scopus, Web of Science, Education Resources Information Centre (ERIC), IEEE Xplore, and ScienceDirect.

These databases were chosen for their extensive coverage of educational research, science, technology, and interdisciplinary studies. The search was conducted in English, articles published between 2000 and 2024. The emergence of digital resources in the early 2000s marked a turning point for educational board games. The widespread adoption of digital technologies in education coincided with the development of digital board games, facilitating a shift from traditional board games to digital platforms. This shift expanded the possibilities for collaborative learning in science education.

Our search strings were developed using keywords derived from our research questions, focusing on three core concepts: 'board games', 'collaborative learning', and 'science education.' We used a combination of Boolean operators (AND, OR) and truncation symbols (*) to broaden the search and capture variations of terms. It is important to note that the complexity and structure of search strings were meticulously tailored to the specific capabilities and limitations of each database. For instance, databases like ScienceDirect may impose restrictions on the number of Boolean operators (e.g. a limit of eight) or have varying support for wildcard characters (*). Other platforms, such as ERIC and ACM Digital Library, might offer more simplified search interfaces with limited options for complex nested queries or specific field targeting beyond basic keywords. This tailoring ensured that the most effective and permissible search was executed within each platform to maximise relevant results. Below are the specific search strings used for each database:

- *Scopus*: ('board game*' OR 'educational game*' OR 'serious game*' OR 'game-based learning') AND ('collaborative learning' OR 'cooperative learning') AND ('science' OR 'biology 'OR 'chemistry' OR 'physics' OR 'STEM' OR 'scientific literacy')
- *Web of Science*: TITLE = Physical Board Games OR Digital Board Games OR 'Science education' AND 'Collaborative'
- *ERIC*: 'board games' AND 'collaborative learning' AND 'science education'
- *IEEE Xplore*: ('board game*' OR 'educational game*' OR 'serious game*' OR 'game-based learning') AND ('collaborative learning' OR 'cooperative learning') AND ('science' OR 'biology OR 'chemistry' OR 'physics' OR 'STEM OR 'scientific literacy')
- *ScienceDirect*: 'board games', digital, physical, 'collaborative learning', AND ('science' OR 'biology 'OR 'chemistry' OR 'physics' OR 'STEM')
- *ACM Digital Library*: 'board games' AND 'science education'

Eligibility criteria

We established clear inclusion and exclusion criteria to ensure the relevance and quality of the selected studies.

Inclusion criteria

- Studies focusing on empirical research, including–but not limited to–randomised controlled trials (RCTs), quasi-experimental designs, observational studies with a clear intervention group and control group, mixed-methods, and qualitative studies.
- Studies investigating the use of paper-based or digital board games as a primary intervention.
- Studies specifically exploring collaborative learning aspects or outcomes.
- Studies conducted within science education. This domain was interpreted broadly to include:
  - General or Interdisciplinary Science: Studies focusing on broad scientific concepts,

scientific inquiry, or integrated science curricula not confined to a single traditional discipline.
  - Specific Core Science Disciplines: Research explicitly focused on Biology, Chemistry, or Physics education.
  - STEM Education: Studies situated in STEM contexts where the primary pedagogical objective or learning outcome was clearly linked to the 'Science' component (e.g. scientific knowledge acquisition, scientific reasoning, or science-specific problem-solving).
- Studies conducted in formal educational settings, such as primary and secondary schools, universities, and structured after-school programmes directly affiliated with or designed as extensions of formal curricula. This excludes informal learning environments, such as general community clubs (e.g. YWCA, 4-H) or recreational summer camps not explicitly linked to an educational institution's curriculum.
- Studies published in English.
- Full-text articles available.
- Studies reporting on quantitative or qualitative outcomes related to collaborative learning, student engagement, learning outcomes, and other relevant educational outcomes.

Exclusion criteria

- Theoretical papers, reviews, meta-analyses, or editorials.
- Studies not involving both board games and collaborative learning.
- Studies not related to science education (i.e. those focusing exclusively on technology, engineering, or mathematics without a significant science component).
- Studies focusing on video games, serious games, or other digital games that do not clearly fit the characteristics of a board game (e.g. complex simulations or role-playing games without board-game mechanics).
- Studies focusing solely on individual learning without any collaborative component.
- Studies not published in peer-reviewed journals.

Study selection process

The study selection process followed the PRISMA guidelines (Page et al., 2021) and is summarised in Figure 1 (PRISMA Flow Diagram).

Identification phase

Our initial comprehensive search across five electronic databases (Scopus, Web of Science, ERIC, IEEE Xplore, and ScienceDirect) yielded a total of 656 records. Specifically, these databases were: Scopus ($n = 214$), Web of Science ($n = 80$), ERIC ($n = 206$), IEEE Xplore ($n = 78$), and ScienceDirect ($n = 47$). An additional 163 records were identified as repetitions of article titles and were subsequently removed.

Screening phase

After removing duplicates, a total of 493 unique records remained. These records underwent a preliminary screening for general conditions. Forty-three articles were excluded because

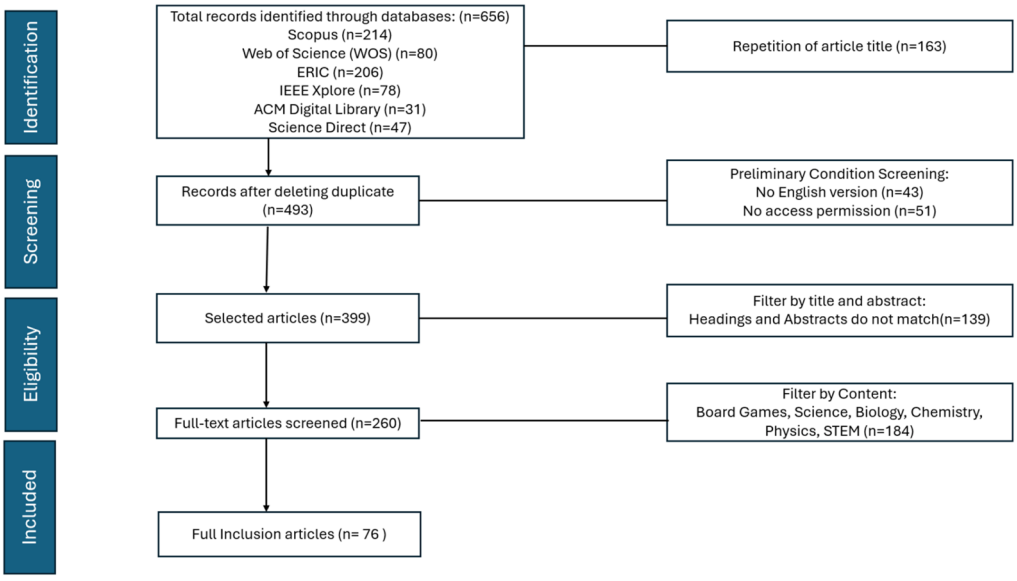

FIGURE 1 Flow diagram detailing the application of PRISMA to studies published between 2000 and 2024.

they did not have an English version, and 51 articles were excluded due to a lack of access permission (e.g. paywall). This initial screening left 399 selected articles for the next stage. Two independent reviewers screened the titles and abstracts of all identified studies. Disagreements between reviewers were resolved through discussion or consultation with a third reviewer.

Eligibility phase

The 399 selected articles proceeded to detailed screening by title and abstract. At this stage, 139 articles were excluded because their headings and abstracts did not match the predefined eligibility criteria. The remaining 260 articles then underwent full-text screening for content by two independent reviewers. During this rigorous content filter, a substantial number of articles (184) were excluded because their primary focus did not align with 'Board Games, Science, Physics, Biology & STEM' as required by our inclusion criteria.

Included phase

Following this comprehensive screening and eligibility assessment, a final total of 76 articles met all inclusion criteria and were selected for full data extraction and synthesis in this systematic review (Appendix A for the final list of articles).

Inter-rater reliability

Title and abstract screening

Two independent reviewers conducted the initial screening of titles and abstracts for the 399 unique records. All disagreements between reviewers were resolved through discussion

and consensus, with consultation from a third reviewer when necessary. This rigorous consensus-based approach was implemented to ensure alignment with the general conditions and preliminary eligibility criteria.

Full-text screening

The 260 articles that proceeded to detailed full-text screening underwent independent review by two reviewers. Inter-rater reliability for this stage was formally calculated using Cohen's Kappa, yielding a coefficient of 0.876. This value indicates substantial agreement between the reviewers (Landis & Koch, 1977), affirming the consistency of the application of our rigorous content filter. Discrepancies identified during this phase were resolved through discussion and consensus between the two reviewers, with a third reviewer consulted for final arbitration if needed.

Data extraction

One reviewer primarily performed data extraction from the 76 included articles to maintain consistency in interpretation. To ensure accuracy and minimise errors, a second reviewer independently cross-checked 100% of the extracted data against the original articles. Any discrepancies identified during this verification process were discussed between the two reviewers and resolved by consensus. While a formal inter-coder reliability coefficient was not calculated, this systematic verification process served as a robust quality control measure for data integrity.

Data extraction and coding

A standardised data extraction form (see Appendix B) was developed collaboratively by the research team and pilot-tested on a small subset of articles to ensure its comprehensiveness and clarity. This form was directly guided by our research questions (RQ1 and RQ2) to ensure all relevant information needed to answer them was systematically captured. Two independent reviewers extracted data from the final set of included articles. To facilitate consistent assessment during data extraction, screening questions adapted from the Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018) were utilised to guide the evaluation of methodological aspects, such as the clarity of research questions and the alignment of collected data with those questions. Any discrepancies encountered during data extraction were discussed and resolved to achieve a complete agreement.

The following data points were extracted for each study:

- *General information*: Authors, publication year, country, educational level (e.g. primary, secondary, higher education).
- *Methodological characteristics* (*for RQ1*): Research design (e.g. quasi-experimental, experimental, mixed-methods, qualitative case study), data collection tools (e.g. surveys, interviews, observations, pre-/post-tests), sample size, and data analysis methods.
- *Board game characteristics* (*for RQ2c*): *Type of board game* (*paper-based, digital*), *game title* (*if specified*): To ensure clarity and consistency in categorisation, especially regarding digital formats, during data extraction, various forms of digital games were consistently grouped under the umbrella of 'Digital Board Games'. This category encompassed computer-assisted games, web-based applications, mobile applications (e.g. Android-system-based), virtual simulations, and augmented reality (AR) based implementations,

provided they maintained core board-game-like characteristics such as turn-based play, distinct game pieces/avatars, and a defined playing area or interface that emulated a board game experience. This unified classification helped to distinguish these digital adaptations from other forms of digital games or simulations not directly modelled after traditional board game structures.

- *Subject area and topics* (*for RQ2a & RQ2b*):
  - For the 'Main Subject/Subject Area' characteristic, studies were categorised based on their primary disciplinary focus or educational context. The categories employed were:
    - *Science* (*general/interdisciplinary*): For studies that addressed science education broadly, did not focus on a single specific discipline, or integrated concepts across multiple sciences (e.g. environmental science, primary science, scientific inquiry skills not tied to one discipline).
    - *Biology*: For studies explicitly focused on biological concepts (e.g. genetics, ecology).
    - *Chemistry*: For studies explicitly focused on chemical concepts (e.g. periodic table, organic chemistry).
    - *Physics*: For studies explicitly focused on physics concepts (e.g. mechanics, electricity).
    - *STEM*: For studies conducted within a broader STEM education framework where the 'Science' component was central to the research, aligning with our inclusion criteria.
    - Specific scientific topics addressed within the game (e.g. cell biology, climate change, chemical reactions).
- *Reported impacts* (*for RQ2d*): Observed outcomes or effects of board game use on collaborative learning and science learning, including both positive effects and identified limitations.

Data analysis

The extracted data were analysed using a combination of quantitative and qualitative methods to address the research questions:

Quantitative analysis

For characteristics such as research designs, data collection tools, sample sizes, board game types, and subject areas (RQ1a–d, RQ2a–c), we used descriptive statistics (frequencies and percentages). This involved counting occurrences of each category and calculating their proportion within the total set of included studies.

Qualitative content analysis

To synthesise the reported impacts of board games (RQ2d), we employed a qualitative content analysis approach. The extracted descriptions of impacts were thoroughly read, and initial codes were generated to capture recurring themes and outcomes. These codes were then grouped into broader categories based on their conceptual similarity (e.g. improved knowledge, enhanced engagement, development of collaborative skills, challenges). The frequency of these emergent themes was then tallied to provide a quantitative overview of the qualitative findings. This process allowed us to identify dominant trends and nuances in the reported effects of board games on collaborative science learning.

RESULTS

This section presents the findings from the systematic review, organised according to the research questions (RQ1 and RQ2). A total of 76 studies met the predefined eligibility criteria and were included in the final synthesis.

Characteristics of included studies (RQ1)

This subsection examines the characteristics of studies investigating the effectiveness of board games in science education, including research methodologies, data collection tools, typical sample sizes, and data analysis methods.

Research methodologies (RQ1a)

Across the 76 included studies, various research methodologies were employed. Quantitative designs were the most prevalent, with 43 studies (56.58%) primarily employing a quantitative approach. This included True Experimental designs ($n = 7$, 9.21%), Quasi-experimental designs ($n = 4$, 5.26%), Non-experimental designs ($n = 17$, 22.37%), and general/unspecified quantitative studies ($n = 15$, 19.74%). Qualitative designs were used in 23 studies (30.26%), encompassing various qualitative methods including case studies. Mixed-methods approaches, combining both quantitative and qualitative methods, were adopted by 10 studies (13.16%). (A detailed breakdown can be found in Table 1).

Data collection methods (RQ1b)

For data collection, pre- and post-tests were the most frequently utilised instruments, employed in 26 studies (34.21%). Questionnaires were also highly common, appearing in 23 studies (30.26%), often complemented by Surveys ($n = 9$, 11.84%). Qualitative data were

TABLE 1 Distribution of research methodologies.

Methodology category	Specific type	Number of studies ($n = 76$)	Percentage (%)
Quantitative	True experimental	7	9.21
	Quasi-experimental	4	5.26
	Non-experimental	17	22.37
	General/unspecified quantitative	15	19.74
	Subtotal quantitative	43	56.58
Qualitative	Case study	4	5.26
	General/unspecified qualitative	18	23.68
	Subtotal qualitative	22	28.95
Mixed-methods	Quantitative and qualitative	10	13.16
Total studies		76	100.00

frequently collected through Interviews ($n = 20$, 26.32%), including semi-structured and focus groups, as well as Observations ($n = 15$, 19.74%). Other tools included written records ($n = 2$), checklists ($n = 2$), rubrics ($n = 2$), and single instances of diagnostic tests, ratings, fieldwork activities, email questionnaires, design artefacts, photo-voice methodology, and conceptual tests. A comprehensive list is provided in Table 2.

Typical sample sizes (RQ1c)

The sample sizes across the 76 studies varied considerably, ranging from a minimum of three participants (ID 8) to a maximum of 697 participants (ID 2, combining government and private school students). Based on the 56 studies with explicit numerical sample sizes, the median sample size was approximately 48.5 participants. The majority of studies involved between 10 and 150 participants (see Table 3 for a distribution of sample sizes).

TABLE 2 Distribution of data collection tools.

Data collection tool	Number of studies ($n = 76$)
Pre-test	26
Post-test	26
Questionnaires	23
Interviews (including focus groups)	20
Observations	15
Surveys	9
Written records	2
Checklists	2
Rubrics	2
Photo-voice methodology	2
Conceptual test	1
Diagnostic test	1
Ratings	1
Fieldwork activity	1
Email questionnaire	1
Design artefacts/documentation	1

Note: Some studies utilised multiple data collection tools; hence, the sum of counts exceeds the total number of studies (76).

TABLE 3 Summary of sample sizes in included studies.

Statistic	Value
Minimum sample size	3
Maximum sample size	697
Median sample size (for $n = 56$ studies with explicit numbers)	48.5
Range	3–697

Note: Sample sizes were extracted from 56 studies where explicit numerical values were provided. Other studies used qualitative descriptors (e.g. 'high school students', 'young learners'), and thus could not be included in the numerical median calculation.

TABLE 4 Distribution of data analysis methods.

Data analysis method	Number of studies ($n = 76$)	Percentage (%)
Descriptive statistics	60	78.95
Qualitative analysis (content/thematic/descriptive)	34	44.74
Inferential statistics	14	18.42

Note: Studies often employed more than one data analysis method, hence the sum of percentages exceeds 100%.

Data analysis methods (RQ1d)

In terms of data analysis, descriptive statistics (including frequencies, percentages, means, standard deviations, and scores) were applied in almost all studies, with 60 studies (78.95%) utilising them. For quantitative data, inferential statistics (such as *t*-tests, ANOVA, ANCOVA, correlations, and regression analysis) were utilised in 14 studies (18.42%). For qualitative data components, Content analysis and Descriptive qualitative analysis were commonly employed, present in 34 studies (44.74%) that used qualitative data collection methods. (A detailed overview of data analysis methods is presented in Table 4).

Subject areas, specific topics, game types, and impacts (RQ2)

This subsection addresses the main subject areas and specific topics in science education where board games are used for collaborative learning, the types of games employed, and their reported impacts.

Main subject areas (RQ2a)

Our analysis of the 76 included studies revealed that General or Interdisciplinary Science was the most frequently studied subject area, accounting for 31 studies (40.79%). This category encompassed research focusing on broad scientific concepts, scientific inquiry skills, or integrated science curricula not specific to a single core discipline (e.g. environmental problems, climate change, scientific literacy, natural science).

Among the specific core scientific disciplines, Chemistry education was most prevalent, featured in 16 studies (21.05%). This was followed closely by Biology, at 15 studies (19.74%), and Physics, at 10 studies (13.16%).

Studies explicitly categorised under STEM education constituted four studies (5.26%) of the primary subject areas, predominantly investigating the science component within broader STEM frameworks (e.g. problem-solving skills in STEM, construction/engineering concepts with a science link). (See Figure 2 for a visual representation of subject area distribution.).

Specific science topics (RQ2b)

Beyond the overarching subject areas, specific scientific topics frequently addressed by board games for collaborative learning across the 76 studies included environmental issues (e.g. climate change, pollution, environmental awareness, biodiversity, sustainability), which appeared as a primary focus in 17 'General Science' studies. Within Biology, topics such as cell and molecular biology, human anatomy, diseases (e.g. COVID-19, taeniasis), and ecosystems were common. In Chemistry, the topics of periodic table, chemical elements, organic chemistry reactions, and mole calculations were prominent. Physics studies

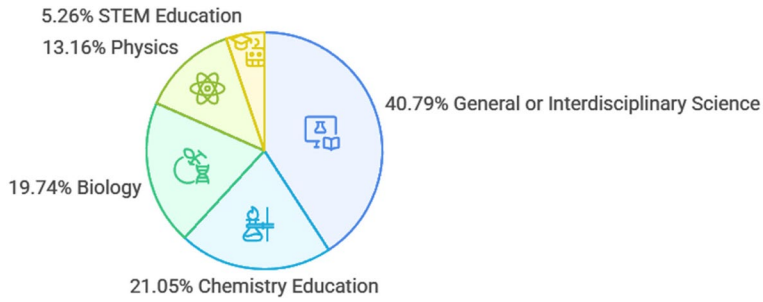

FIGURE 2 Distribution of main subject areas in studies.

often concentrated on energy efficiency, the solar system/astronomy, waves, electricity, and quantum science.

Types of board games (RQ2c)

Regarding the type of board games utilised across the 76 included studies, physical board games were the dominant format, identified in 53 studies (69.74%). Digital board games were used in 23 studies (30.26%), encompassing various forms, such as web-based, virtual, AR-based mobile, Android system-based, and computer-assisted games.

Reported impacts of board games on collaborative science education (RQ2d)

The analysis of the 76 included studies revealed a consistent range of reported positive impacts of board games on collaborative learning and science education outcomes, alongside some identified limitations. These impacts can be broadly categorised into three main themes: Enhanced Learning and Conceptual Understanding, Improved Engagement and Attitudes, and Development of Collaborative and Other Skills.

Enhanced learning and conceptual understanding

A significant majority of studies reported that board games contributed positively to students' understanding of scientific concepts and knowledge retention. This was evidenced by improvements in test scores, higher exam grades, and qualitative indications of deeper conceptual understanding. This impact was reported in 34 studies (44.74%) (e.g. ID 2, 7, 8, 14, 16, 18, 20, 23, 26, 31, 33, 37, 39, 40, 42, 45, 47, 49, 50, 51, 52, 54, 55, 56, 57, 59, 62, 66, 70, 71, 72, 74, 75, 76). Collaborative gameplay often facilitated peer-to-peer explanations and the active construction of knowledge, particularly in complex topics such as molecular biology, chemistry concepts, and physics principles.

Improved engagement, motivation, and attitudes

Board games consistently emerged as highly motivating and engaging tools in science education. This impact was noted in 27 studies (35.53%) (e.g. ID 4, 5, 6, 7, 12, 17, 22, 29, 32, 35, 37, 42, 44, 45, 46, 47, 57, 59, 60, 62, 63, 65, 67, 68, 69, 72, 75). This enhanced motivation was attributed to the games' intrinsic appeal, competitive elements, and the inherent social nature of collaborative play. Some studies specifically highlighted positive emotional shifts during the learning process (ID 32, 72).

Development of collaborative and other skills

A substantial number of studies highlighted the role of board games in fostering essential collaborative and transferable skills. This impact was reported in 13 studies (17.11%) (e.g. ID 10, 11, 27, 30, 36, 46, 48, 53, 55, 61, 69, 73, 75). These included improvements in communication, teamwork, problem-solving in groups, negotiation, critical thinking, system thinking, and, in the case of pre-service teachers, pedagogical content knowledge.

Challenges and limitations

Although positive impacts were prevalent, the included studies consistently reported various challenges and limitations, providing valuable insights for future research and practice. These primarily included issues related to game design and implementation, such as overly complex game rules (ID 23), game mechanics being harder to grasp than content (ID 20), difficulties in balancing competition with collaboration (ID 11), challenges in integrating games with existing curricula (ID 21, 65), and the need for careful design refinement (ID 30). Methodological limitations of the studies were also common, including reliance on qualitative analysis only (ID 14, 37, 67, 68, 71), small sample sizes (e.g. ID 5, 8, 19, 25, 26, 35, 42, 63), lack of control groups (ID 54), short intervention durations and absence of long-term retention evaluations (ID 6, 9, 15, 23, 41, 45, 56), and not assessing baseline emotional states (ID 32, 73). Furthermore, constraints on scope and generalisability were noted, as studies often focused on single board game themes (ID 40), specific age groups, or narrow topics, limiting the broader applicability of findings. Finally, several studies highlighted neglected aspects, such as not exploring teacher motivations (ID 33, 61), the broader societal context (ID 10), or how games translate ideas into functional applications (ID 27).

DISCUSSION

This systematic review examined the use of board games for collaborative learning in science education, synthesising findings from empirical studies published between 2000 and 2024. The analysis of 76 articles revealed several significant findings that enhance our understanding of this innovative pedagogical approach.

Focus on science education and subject area distribution

Our findings reveal a clear distribution across the various categories within science education. General or Interdisciplinary Science emerged as the most frequently investigated subject area, accounting for 31 studies (40.79%) of the included studies. This indicates a substantial focus in the existing literature on board games that address broad scientific concepts, scientific inquiry skills, or integrated science curricula, rather than being confined to a single traditional discipline. This finding aligns with the broader emphasis on developing scientific literacy and interdisciplinary thinking in contemporary education (Kara, 2021; Küçükşen Öner et al., 2024; Othman & Sim, 2024; Teixeira & Vasconcelos, 2024).

Among the specific core scientific disciplines, Chemistry education was the most prevalent, featured in 16 studies (21.05%). This finding aligns with the growing body of research highlighting the potential of game-based learning to address the abstract and complex nature of chemistry concepts (da Silva Júnior et al., 2023; Hou et al., 2023). Biology (15 studies, 19.74%) and Physics (10 studies, 13.16%) also represented significant portions of the literature, demonstrating the applicability of board games across various scientific fields. Studies explicitly categorised under STEM education constituted a smaller portion (four studies, 5.26%) of the primary subject areas, predominantly investigating the science component

within broader STEM frameworks. This distribution underscores the versatility of board games in supporting diverse learning objectives across the spectrum of science education.

Quantitative research and questionnaires dominate

The review found that quantitative research designs were the most prevalent methodology, primarily employed in 43 studies (56.58%). Within these, non-experimental designs were particularly common. This dominance of quantitative approaches, as noted in previous research on board games in science education (Kalogiannakis et al., 2021; Teixeira & Vasconcelos, 2024; Wang & Zheng, 2021), might be attributed to the relative ease of data collection and analysis for measuring learning outcomes and attitudes on a larger scale.

Consistent with this, questionnaires and surveys were the most commonly used data collection tools, appearing in 23 studies (30.26%) and nine studies (11.84%), respectively. While these tools are efficient for gathering self-reported data and assessing learning gains, the prevalence of quantitative descriptive analysis (60 studies, 78.95%) suggests a focus on summarising and describing data rather than extensive inferential statistical analysis (14 studies, 18.42%). Future research could benefit from incorporating more qualitative approaches (used in 23 studies, 30.26%) to better understand the nuances of student experiences and collaborative interactions within board game environments.

Sample size and data analysis

The sample sizes across the reviewed studies varied considerably, ranging from three to 697 participants. The median sample size was approximately 48.5 participants (based on 56 studies with explicit numerical values), with the majority of studies involving between 10 and 150 participants. This range, consistent with other studies on board games in science education (Hashim et al., 2024; Holincheck et al., 2024; Küçükşen Öner et al., 2024), indicates a mix of smaller-scale exploratory studies and larger interventions. While larger sample sizes can enhance generalisability, smaller studies can still offer valuable in-depth insights, particularly when employing qualitative methodologies.

As noted, descriptive statistics were the most frequently utilised data analysis method (60 studies, 78.95%), focusing on summarising characteristics and outcomes. Qualitative analysis methods, including content and descriptive analysis, were also widely employed (34 studies, 44.74%), particularly in studies aimed at exploring student experiences and interactions. This prevalence of descriptive approaches, aligning with other review studies on board game research (Teixeira et al., 2024; Zhan et al., 2024), suggests a foundational stage of research where the primary goal is to characterise the landscape and initial impacts of board games in science education.

Board game types and the role of mechanisms

Physical board games were the overwhelmingly dominant format, identified in 53 studies (69.74%). This finding is consistent with several previous studies where researchers also primarily employed physical board games (Hursen & Bas, 2019; Kodalle, 2022; Li et al., 2022). The comparatively limited use of digital board games (13 studies, 17.11%) may be due to various factors, including restrictions on electronics in educational settings or challenges related to access and infrastructure (Syahraz Abdul Razakek et al., 2024). Pedagogical reasons, such as the perceived effectiveness of physical interaction for

fostering direct collaboration and communication, may also contribute to this preference (Russo et al., 2024). It is essential to reiterate that our categorisation of digital board games in this review encompassed various forms, including web-based, virtual, AR-based mobile, Android system-based, and computer-assisted games, provided they retained core board-game-like characteristics.

A significant limitation of the current literature, and therefore of this review, is the infrequent detailed reporting and analysis of specific game mechanisms (e.g. cooperative versus competitive elements, resource management, negotiation mechanics, role-playing) within the included studies. Although our review categorised games by format (physical versus digital), a deeper understanding of how these underlying mechanisms influence collaborative learning outcomes is essential for progress in the field. Future research should focus on systematic data extraction and analysis of these mechanisms to gain more detailed insights into their effects on collaborative science learning.

Overall effectiveness and future directions

The studies reviewed collectively suggest that board games can be a valuable tool for science education, demonstrating both effectiveness and certain limitations.

Board game effectiveness in science education

This review provides robust evidence that board games are a powerful tool for promoting science learning across various subjects and age groups. From elementary school settings to universities, board games effectively enhance student understanding of scientific concepts in biology, chemistry, physics and beyond. The review highlights several key advantages board games offer students:

Firstly, board games can significantly improve students' knowledge acquisition and conceptual understanding. This was the most frequently reported impact, evident in 34 studies (44.74%), which documented improvements in test scores, higher exam grades, and qualitative indications of deeper conceptual understanding (e.g. ID 2, 7, 8, 14, 16, 18, 20, 23, 26, 31, 33, 37, 39, 40, 42, 45, 47, 49, 50, 51, 52, 54, 55, 56, 57, 59, 62, 66, 70, 71, 72, 74, 75, 76). By requiring players to apply their knowledge and make strategic decisions, board games encourage them to think critically and creatively to solve problems and advance in the game (Botes, 2024; Chukusol et al., 2024). Research by Lin and Hou (2024a) and Machuqueiro and Piedade (2024) further suggests that board games encourage strategic decision-making, a crucial skill for scientific inquiry.

Secondly, board games consistently make learning science more enjoyable and engaging, leading to increased positive emotions and motivation. This impact was noted in 27 studies (35.53%) (e.g. ID 4, 5, 6, 7, 12, 17, 22, 29, 32, 35, 37, 42, 44, 45, 46, 47, 57, 59, 60, 62, 63, 65, 67, 68, 69, 72, 75). This creates a more positive learning environment that can enhance student engagement with science (Assapun & Thummaphan, 2023; Ezezika et al., 2023; Holincheck et al., 2024; Küçükşen Öner et al., 2024; Saithongdee & Sirirat, 2024).

Thirdly, board games contribute to the development of collaborative and other essential science skills. This impact was reported in 13 studies (17.11%) (e.g. ID 10, 11, 27, 30, 36, 46, 48, 53, 55, 61, 69, 73, 75). These include scientific inquiry skills (Ezezika et al., 2023; Hou, 2023), communication, teamwork, group problem-solving, negotiation, and systems thinking. They can also provide valuable assessment knowledge for science teachers (Botes, 2024). Students often find board games helpful for learning science content, and report positive perceptions of the experience (Malicoban, Bulado, et al., 2021;

Othman & Sim, 2024; Saithongdee & Sirirat, 2024; Teixeira & Vasconcelos, 2024). This improved self-efficacy can further motivate students to engage with science learning. Finally, board games can foster collaboration and interaction between adults and children, creating a valuable space for shared learning and promoting STEM education (Arboleya-García & Miralles, 2022; Bustamante et al., 2020; Salgado-Jauregui et al., 2022). This collaborative aspect can benefit younger students who can learn from interacting with adults.

Effectiveness across grade levels and formats

The reviewed studies explored the use of board games in various educational settings, ranging from elementary schools to universities. Evidence suggests that board games can be effective across these grade levels, with both digital and physical formats yielding positive results. However, some limitations and gaps were identified. Many studies employed relatively small sample sizes (Botes, 2024; da Silva Júnior et al., 2023; Montejo Bernardo & Fernández González, 2021; Saithongdee & Sirirat, 2024), which may limit the generalisability of their findings.

Additionally, a significant gap in the literature is the limited investigation into the long-term retention of knowledge gained through board games. While some studies reported positive short-term effects (e.g. Apostolellis et al., 2018; Meya & Eisenack, 2018), there is a lack of research on whether these benefits persist over time (Fjællingsdal & Klöckner, 2020; Goncharova, 2012; Montejo Bernardo & Fernández González, 2021; Tsai et al., 2021). Understanding long-term knowledge retention is crucial for definitively evaluating the effectiveness of board games as a sustainable learning tool. Furthermore, many studies did not utilise control groups (Bortoli et al., 2023; Holincheck et al., 2024; Ramos et al., 2024), making it difficult to isolate the specific impact of the board game intervention on learning outcomes.

While cost-effectiveness was not a primary focus of the reviewed studies, some studies did explore whether board games could be a cost-effective way to supplement science learning compared to traditional methods (Apostolellis et al., 2018; McOwat & Stanley-Wall, 2018; Shemran et al., 2017). Similarly, teacher training was not extensively explored, though a few studies discussed the need for training on incorporating board games effectively (Botes, 2024; Holincheck et al., 2024; Küçükşen Öner et al., 2024) or explored specific instructional strategies that work well with board games. Finally, beyond engagement, some studies investigated broader changes in student attitudes towards science after using board games (Dziob, 2020; Montejo Bernardo & Fernández González, 2021; Tsai et al., 2021).

Focus beyond science and collaborative learning design

While science emerged as the dominant subject area in this review, the included studies did not extensively explore the application of board games for collaborative learning in other disciplines, such as mathematics or social studies. This represents an opportunity for future research to explore the potential of board games in fostering collaboration across the curriculum. Furthermore, a deeper analysis of the specific collaborative learning strategies embedded within the board game designs themselves (e.g. cooperative vs. competitive elements, explicit group discussion prompts, negotiation mechanics) was not a primary focus of the reviewed studies. Analysing these design elements can reveal how games actively promote collaboration and how these strategies impact student learning. Additionally, the role of the teacher in facilitating collaborative learning during board game use was not consistently explored across the reviewed literature. Exploring these teacher facilitation strategies

could provide valuable insights for educators seeking to optimise the collaborative learning potential of board games in their classrooms.

Learning outcomes beyond knowledge gain and assessment methods

The studies reviewed primarily focused on knowledge gain as a learning outcome. However, some studies have explored how board games impact other scientific competencies—such as scientific reasoning, communication skills, or scientific inquiry skills–during gameplay. Analysing these studies can provide a more comprehensive picture of the learning benefits associated with board games in science education. The studies employed various assessment methods (tests, observations) to measure the effectiveness of board games. While this variation allows for a multifaceted understanding of learning outcomes, it can also make comparisons across studies challenging. Future research that explores standardised assessment methods specifically designed for board game-based learning could be beneficial.

CONCLUSION AND FUTURE WORKS

This article systematically reviewed the application of board games for collaborative learning in science education. Seventy-six empirical studies published between 2000 and 2024 were selected based on specific inclusion and exclusion criteria, meticulously following the PRISMA guidelines. The review focused on analysing the main subject areas and examined topics, research methodologies, data collection tools, sample sizes, data analysis methods, findings, and game types used in these articles.

Addressing the research questions provides valuable insights and understanding regarding the use of board games for collaborative learning in science education. Key patterns, trends and findings emerged through the analysis of the selected articles, shedding light on the effectiveness, methodologies and outcomes of integrating board games into collaborative science learning. Furthermore, the findings derived from investigating these research questions contribute to the overall understanding of the current research landscape in this domain and provide valuable insights for educators, researchers and practitioners interested in utilising board games for collaborative learning in science education.

The analysis findings indicated that general or interdisciplinary science education was the most researched subject category among the selected articles (31 studies, 40.79%), confirming the widespread application of board games across diverse scientific contexts. Within specific disciplines, chemistry education emerged as the most investigated topic (16 studies, 21.05%). A quantitative design was the most preferred approach for research methodologies (43 studies, 56.58%), although various methods were used. Pre- and post-tests (26 studies, 34.21%) and questionnaires (23 studies, 30.26%) were the most commonly employed data collection tools. Most of the studies had sample sizes with a median of approximately 48.5 participants. Descriptive statistics were found to be the most common for data analysis (60 studies, 78.95%). Physical board games were the most frequently used type in science education (53 studies, 69.74%), while digital board games (13 studies, 17.11%) had limited representation, likely due to the restrictive use of electronic devices in educational settings and a historical preference for physical formats.

The review highlights that board games are effective tools for enhancing scientific knowledge acquisition and conceptual understanding (34 studies, 44.74%), improving student engagement, motivation, and attitudes towards science (27 studies, 35.53%), and fostering the development of collaborative and other essential science skills (13 studies, 17.11%). However, the review also identified critical limitations in the existing literature, including a

prevalence of small sample sizes, a lack of long-term effectiveness studies, and insufficient focus on specific game mechanisms.

Future research directions: Optimising board game integration and theoretical frameworks

Based on the findings and identified gaps of this systematic review, several key research suggestions are proposed to advance the field. Future research should delve deeper into how specific game mechanisms (e.g. cooperative vs. competitive elements, negotiation, resource management, role-playing) within board games influence different facets of collaborative learning and science outcomes, requiring more granular data extraction and analysis of game design. While the potential is clear, more empirical studies are needed that explicitly measure and report on the development of collaborative learning skills (e.g. communication, teamwork, conflict resolution, shared problem-solving) as distinct learning outcomes, rather than solely focusing on science content knowledge. A critical gap is also the lack of research on the long-term impact of board games on knowledge retention and sustained changes in attitudes or behaviours (Cardinot & Fairfield, 2022; Mostowfi et al., 2016; Trevino et al., 2016); thus, longitudinal studies are essential to understand the lasting benefits. Methodological rigour should be enhanced, with future studies prioritising more robust research designs, including the consistent use of control groups to isolate intervention effects, and the application of inferential statistical analyses (e.g. correlations, regression, non-parametric tests, factor analysis, MANOVA/MANCOVA) to move beyond descriptive findings (Eriksson et al., 2021; Hernán et al., 2019; Kara, 2021; León et al., 2022; Petri & von Wangenheim, 2016; Treiblmaier & Filzmoser, 2010). Research should also broaden its scope to include diverse sample groups, such as preschool children (Mostowfi et al., 2016), nursery school children (Cheung & McBride, 2017), and disabled students (Assapun & Thummaphan, 2023), as well as a wider range of educational contexts beyond elementary and secondary schools (Hwang et al., 2016; Ramesh & Sadashiv, 2019; Tsai et al., 2020). Given the limited representation of digital board games, further exploration of their potential for science learning is crucial, including investigating their accessibility, broader implementation, and integration with emerging technologies such as Virtual Reality (VR) (Arici et al., 2019), Augmented Reality (AR) (Abdullah et al., 2022), and mobile applications (Ismail et al., 2018). Furthermore, future research should delve deeper into the theoretical underpinnings of why board games are effective in science education, drawing on relevant learning theories and pedagogical frameworks, and examine practical strategies for effectively integrating board games into existing science curricula, aligning them with specific learning objectives and broader curriculum goals. Beyond knowledge gain, studies should explore the impact of board games on other scientific competencies (e.g. scientific reasoning, communication skills, scientific inquiry skills) and develop standardised assessment methods specifically designed for board game-based learning. Finally, more research is needed on effective teacher training programmes for incorporating board games into classrooms and the specific teacher facilitation strategies that optimise collaborative learning during gameplay.

AUTHOR CONTRIBUTIONS

Mohd Kamal Othman: Conceptualization; validation; funding acquisition; supervision; data curation; formal analysis; project administration; writing – original draft; writing – review and editing; methodology. **Rahimah Mat:** Funding acquisition; writing – review and editing; validation; project administration; methodology. **K. C. Sim:** Investigation; data curation; formal analysis; writing – original draft.

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CONFLICT OF INTEREST STATEMENT

On behalf of all authors, the corresponding author states that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

We adhered to the PRISMA 2020 guidelines for systematic reviews (Page et al., 2021).

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APPENDIX A

A complete list of selected articles in this review

ID	Article title	Reference
ID01	A group learning support system enhancing the externalisation of thinking	Kusunoki et al. (2002)
ID02	Discovering the cell: an educational game about cell and molecular biology	Spiegel et al. (2008)
ID03	Just working with the cellular machine: a high school game for teaching molecular biology	Cardoso et al. (2008)
ID04	A board game about space and solar system for primary school students	Kirikkaya et al. (2010)
ID05	Vegetation interaction game: Digital SUGOROKU of vegetation succession for children	Deguchi et al. (2010)
ID06	Taking attention on environmental issues by an attractive educational game: Enviropoly	Arslan et al. (2011)
ID07	An online game approach for improving students' learning performance in web-based problem-solving activities	Hwang et al. (2012)
ID08	Organic mastery: An activity for the undergraduate classroom	Mosher et al. (2012)
ID09	Planet play: designing a game for children to promote environmental awareness	Goncharova (2012)
ID10	A climate change board game for interdisciplinary communication and education	Eisenack (2013)
ID11	Collaborative gaming: Teaching children about complex systems and collective behaviour	Peppler et al. (2013)
ID12	Education for energy efficiency through an educational game	Mesquita et al. (2013)
ID13	Using educational games to engage students in veterinary basic sciences	Buur et al. (2013)
ID14	Developing and playing chemistry games to learn about elements, compounds, and the periodic table: Elemental Periodica, Compoundica, and Groupica	Bayir (2014)
ID15	Designing playful learning by using educational board games for children in the age range of 7–12: (a case study: recycling and waste separation education board game)	Mostowfi et al. (2016)
ID16	Effects of an augmented reality-based educational game on students' learning achievements and attitudes in real-world observations	Hwang et al. (2016)
ID17	Key factor to improve Adversity Quotient in children through mobile game-based learning	Boonsamuan and Nobaew (2016)
ID18	The effectiveness of an educational game for teaching optometry students basic and applied science	Trevino et al. (2016)
ID19	Developing a framework to better engage students in STEM via game design: Findings from Year 1	Shemran et al. (2017)
ID20	The development of inquiry by using android-system-based chemistry board game to improve learning outcome and critical thinking ability	Wardani et al. (2017)
ID21	'Pump that press!' design evaluation of audience interaction using collaborative digital and physical games	Apostolellis et al. (2018)
ID22	Biofilm building: a simple board game to reinforce knowledge of biofilm formation	McOwat and Stanley-Wall (2018)

ID	Article title	Reference
ID23	Board game in physics classes—A proposal for a new method of student assessment	Dziob (2020)
ID24	Effectiveness of gaming for communicating and teaching climate change	Meya and Eisenack (2018)
ID25	'If You Add Too Much Science, It Gets Boring.' Exploring students' conceptual change through their game design iterations	Hovey et al. (2018)
ID26	The use of monopoly-like games (MLG) to promote qualified scores for three student competencies	Fauziah et al. (2018)
ID27	A board-game for co-designing smart nature environments in workshops with children	Gennari et al. (2019)
ID28	Essentials of gamification in education: a game-based learning	Ramesh and Sadashiv (2019)
ID29	Introducing an inquiry-based experiment-integrated science game for elementary students: The shadow races game	Bayir (2019)
ID30	Last Island: exploring transitions to sustainable futures through play	Taghikhah et al. (2019)
ID31	Using board games to teach socioscientific issues on biological conservation and economic development in Taiwan	Tsai et al. (2019)
ID32	Effects of games on students' emotions of learning science and achievement in chemistry	Chen et al. (2020)
ID33	Element enterprise tycoon: Playing board games to learn chemistry in daily life	Tsai et al. (2020)
ID34	Green across the board: Board games as tools for dialogue and simplified environmental communication	Fjællingsdal and Klöckner (2020)
ID35	Supplementing elementary science learning with multi-player digital board game: A pilot study	Premthaisong and Srisawasdi (2020)
ID36	Board game design: an educational tool for understanding environmental issues	Parekh et al. (2021)
ID37	Chemical battleship: discovering and learning the periodic table playing a didactic and strategic board game	Montejo Bernardo and Fernández González (2021)
ID38	Development of a STEM board game electriciladders for Grade 8 students	Malicoban, Bulado, et al. (2021)
ID39	Enhancing cognitive development in learning chemical symbols and periodicity through instructional games	Aliyu et al. (2021)
ID40	Using a board game to teach about sustainable development	Tsai et al. (2021)
ID41	Using a cooperative educational game to promote pro-environmental engagement in future teachers	Vázquez-Vílchez et al. (2021)
ID42	Design and evaluation of a board game in food and nutrition education	Chiang et al. (2022)
ID43	Development and application of an environmental education tool (board game) for teaching integrated resource management of the water cycle on coral reef islands	Shimabukuro et al. (2022)
ID44	Edutainment, tools and methods in high school education development of ATCG (ATtack Covid Game) online and electronic board games	Soewono et al. (2022)
ID45	Game-based learning to engage students with physics and astronomy using a board game	Cardinot and Fairfield (2022)
ID46	Pre-service teachers' experiences on the development of educational science board games	Botes (2022)

ID	Article title	Reference
ID47	The 'Sciencemopoly Game' to improve junior high school students' learning motivation on the digestive system topic	Hayati et al. (2022)
ID48	Assessing the effectiveness of board game-based learning for enhancing problem-solving competency of lower secondary students	Assapun and Thummaphan (2023)
ID49	Development of a STEM board game on waves for Grade 7 students	Malicoban, Eguia, et al. (2021)
ID50	The design and evaluation of a gamification teaching activity using board game and QR code for organic chemical structure and functional groups learning	Wu et al. (2018)
ID51	The development and evaluation of an educational board game with augmented reality integrating contextual clues as multi-level scaffolding for learning ecosystem concepts	Wang et al. (2019)
ID52	The effect of 3D Electronic Board Games in enhancing elementary students learning performance on human internal organs	Zheng et al. (2018)
ID53	SNaP 2: the evolution of a board game for smart nature environments	Gennari et al. (2019)
ID54	A preliminary study to assess the use of a 'Snakes and Ladders' board game in improving the knowledge of elementary school children about taeniasis	Wulanyani et al. (2019)
ID55	The effect of a scientific board game on improving creative problem-solving skills	Chen et al. (2021)
ID56	The pedagogical impact of board games in public health biology education: the Bioracer Board Game	Ezezika et al. (2023)
ID57	An educational game for teaching osmolarity and tonicity: opinions of dental and medical students	Pessoa et al. (2023)
ID58	Chemical Quest: general knowledge and popular culture quizzes about the elements in a board game for the class	Bortoli et al. (2023)
ID59	Learning mole calculation through a board game in an engaging and enjoyable environment: Design, implementation, and evaluation	Saithongdee and Sirirat (2024)
ID60	CR322: A web-based board game for aiding students in reviewing chemical reactivity	da Silva Júnior et al. (2023)
ID61	Demonstrating pedagogical content knowledge through the development of educational science board games	Botes (2024)
ID62	I arrived at the sun! Developing an educational board game with the collaboration of pre-service art and pre-service science teachers	Küçükşen et al. (2024)
ID63	Exploring Malaysian school children's perception of the advantages and disadvantages of the ToothPoly board game: a qualitative study	Syahraz Abdul Razakek et al. (2024)
ID64	The development and evaluation of an educational board game on basic geotechnical soil characterisation	Chrusciak et al. (2024)
ID65	Quantum science and technologies in K-12: Supporting teachers to integrate quantum in STEM classrooms	Holincheck et al. (2024)
ID66	Using BioBoard-G: A board game for enhancing understanding of cell division for secondary school	Hashim et al. (2024)
ID67	'CARBGAME' (CARd & Board GAmes in Medical Education): a gamification innovation to foster active learning in biochemistry for medical students.	Surapaneni (2024)

ID	Article title	Reference
ID68	Activity proposals to improve children's climate literacy and environmental literacy	Ramos et al. (2024)
ID69	More than just a game: Transforming social interaction and STEM play with Parkopolis	Bustamante et al. (2020)
ID70	Learning outcomes of the educational board game 'Taphonomy: Dead and Fossilised' were evaluated with high school learners in a summertime programme	Salgado-Jauregui et al. (2022)
ID71	'The Game of the Sea': an interdisciplinary educational board game on the marine environment and ocean awareness for primary and secondary students	Arboleya-García and Miralles (2022)
ID72	Effects of games on students' emotions of learning science and achievement in chemistry	Chen et al. (2020)
ID73	Questions in a life-sized board game: comparing caregivers' and children's question-asking across STEM museum exhibits	Gaudreau et al. (2021)
ID74	The impacts of a marine science board game on motivation, interest, and achievement in marine science learning	Lin et al. (2019)
ID75	Developing a European-style board game to teach organic chemistry	Triboni and Weber (2018)
ID76	Element Cycles: An environmental chemistry board game	Pippins et al. (2011)

APPENDIX B

Detailed analysis of the selected articles

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
01	Environmental problems (S)	Do not support child learners, and the combination of education with gameplay is unsuccessful	Quantitative (true experimental)	Questionnaires	23 pupils (5th grade) primary school (age 11)	Descriptive (frequencies)	Board games with computer simulations	High interest in board game pieces	It focused on the overall effectiveness of board games, neglecting learner-centred design aspects
02	Cell and molecular biology (B)	Low reasoning and interactivity in the classroom challenge students to collect, discuss, and interpret clues from Biology questions	Quantitative (true experimental)	Questions (Difficulty Levels)/ Questionnaire	370 public school students, 327 private school students (ages 15–19)	Descriptive: Percentages/ Inferential: Correlations	Paper-based board games about cell and molecular biology	Learned new biological concepts	Did not focus on the development and evaluation of games based on cooperative strategies for teaching biology
03	Molecular biology (B)	Struggling to understand DNA function, origin, and its relationship with proteins	Quantitative (Non-experimental)	Questionnaire	10 biology teachers, 32 students (16–19years private high school)	Descriptive: Frequencies/ Percentages	Paper-based interdisciplinary board game (immune system response)	Students found it good and useful	Limited their investigation to core molecular biology topics
04	Space and solar system (P)	Grade anxiety makes students see evaluation as a threat	Qualitative: Case study	Semi-structured interviews	16 Science and Technology teachers, 40 7th-grade students	Descriptive	Paper-based educational board game	Teachers found it applicable, and students enjoyed it	Compared student performance in the game activity to their performance in other activities
05	Vegetation succession (B)	Students showed difficulty grasping the concept of vegetation succession	Quantitative: Non-experimental	Questionnaire/ Fieldwork activity	17 sixth-grade children (age 12) at a Japanese elementary school	Descriptive	Digital Sugoroku board game (Mt. Rokko forest simulation)	Positive responses to questionnaire items	The sample population was limited to elementary school children in Japan

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
06	Environmental literacy (S)	Low level of environmental literacy	Qualitative	Focus interviews/ discussions/ observation	44 undergraduate pre-service teachers (ages 20–45)	Descriptive	Paper-based enviropoly board game (sea animals)	Attractive, motivating, enjoyable, adaptable	Investigated the long-term effectiveness of the game in enhancing students' environmental knowledge, attitudes, and beliefs and promoting behaviour change
07	Natural science course (S)	Low learning achievements, flow experiences and learning attitudes of students in science learning	Quantitative: Experimental, − Quasi-experimental	Learning achievement tests/ Questionnaires	50 elementary school students, Taiwan (5th & 6th grade, ages 11–12)	Descriptive: Mean/SD; Inferential: *t*-tests/ANCOVA	Competitive board game (web-based problem-solving board games)	Improved flow experience, learning attitudes, interest, technology acceptance, and achievement	A limited number of participants and the short time to conduct this study
08	Organic chemistry course (reactions) (C)	Implementation of alternative instructional modes has been hindered	Quantitative: Non-experimental	Questions	Three to six students (ages 19–20)	Descriptive: Frequencies/ Percentages	Physical board game (course trivia and concepts)	Higher exam grades compared to standard review sessions	Limited to the undergraduate organic chemistry classroom
09	Environmental preservation/ awareness (S)	Limited opportunities to train the children to understand environmental issues	Quantitative/ Qualitative	Literature review/ visual analysis/ workshops	20–30 fourth grade students (age 10)	Visual analysis of environmental games	Educational board games: Environmentally related board game (Planet Play)	Literature review and visual analysis only	The long-term benefits of playing environmental games remain unclear. Additionally, the large-scale integration of educational games into school curriculums is a recent phenomenon, further limiting long-term data

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
10	Climate change (S)	A critical need exists for strengthened communication at the science-policy interface. This is essential to bridge the gap between interdisciplinary research and current policy instruments for tackling environmental challenges	Qualitative	Qualitative email questionnaire/ Observation	25 schools students (age 15–18) & universities (ages 20–30)	Qualitative (descriptive)	Paper-based: KEEP COOL board game	The board game contributed to teaching and communicating climate change/ provides a basis for interdisciplinary collaboration and transdisciplinary activities	Did not explore the broader societal context of raising environmental awareness, promoting public understanding of science, and the role of public relations in these efforts
11	Advanced science content (S)	Collaborative board games may be less suitable for teaching highly complex scientific concepts to young children (ages 6–9) due to their developmental stage	Quantitative/ Qualitative	Teachers' observations/ Video transcription and coding	40 students (Grades 1–2, ages 6–9)	Descriptive frequencies)/ Qualitative (Descriptive)	Paper-based: HIVEMIND board game	Significantly make positive comments to others, talk on-topic, read instructions to other players, gaze towards the board as well as other players, and take shorter turns, among other findings	Did not consider the interplay between students' emotional engagement (affective outcomes), learning achievements, and their perception of the coherence between the game's theme and its mechanics
12	Physics (energy efficiency) (P)	Limited chance to explore virtual board games to learn energy efficiency	Quantitative (non-experimental)	Questionnaire	43 students from a class of a junior high public school in the state of Sao Paulo (ages 13–15)	Descriptive: frequencies	Computer virtual board game	A significant majority of students liked the game, felt motivated, and found topics current and interesting	Limited opportunities to explore virtual board games as a tool for learning about energy efficiency

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
13	Food-borne disease (S)	Veterinary education faces challenges in incorporating student-centred learning approaches into the basic science curriculum	Qualitative	Observation	114 of the 200 faculty and staff (ages 25–55)	Qualitative (descriptive)	'Foodborne Outbreak Clue' card game	Anecdotal feedback from students suggests they enjoyed the activities and developed a better understanding	Only surveyed faculty and staff, excluding student perspectives in gathering data for the results
14	Elements, Compounds and the periodic table (C)	There's a scarcity of educational board games specifically designed to teach students about elements, compounds, and the periodic table	Qualitative	Written records (codes and themes or categories)	250 students (grades 9–12), 30 in-service and pre-service teachers (Ages 18–20)	Qualitative (content analysis)	*Paper-based*: *Compoundica* board game	The game provides an entertaining way to facilitate students' learning about elements, compounds and the periodic table	Relied on qualitative analysis, neglecting to explore quantitative data such as pre-test and post-test scores to assess the intervention's impact
15	Recycling and waste separation (S)	Elementary school curriculums often lack in-depth education on proper recycling practices	Qualitative (Case study)	Focus group/ Fun toolkit/game checklist	20 students (ages 7–12)	Descriptive (Mean/SD)/ Inferential (Non-parametric tests)	Educational board game: Computer games	Fun Toolkit and This or That method showed similar results and established a preference for one game	To assess the long-term effectiveness of the board game as a learning tool, it is recommended to test it over an extended period and compare its impact with traditional lecture styles
16	Ecology (S)	Low learning attitudes and performance in real-world observations	Quantitative (Experimental)—Quasi-experimental	Pretest and Posttest/ Questionnaire	57 fifth graders of elementary school (age 11)	Descriptive (Mean/SD)/ Inferential (ANCOVA)	AR-based Mobile Game	Improved learning attitudes and performance on a field trip	The board game's effectiveness could be explored in a wider range of courses, such as social studies and environmental science
17	Solar system (P)	Low motivation in learning Adversity Quotient (AQ) among primary school students	Quantitative (Experimental)—Quasi-experimental	Questionnaire	40 students at primary school in Chiang Rai (ages 7–12)	Descriptive (Mean)/ Inferential (*t*-test)	'It's here' mobile board game	The strategy environment is the key factor for improvement in science achievement	The study design did not focus on optimising the game mechanics for a more engaging learning experience

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
18	Optometry (P)	The application of games for learning within optometry curricula remains an under-researched area/	Quantitative (Experimental)—Quasi-experimental	Pre-test and Posttest/Survey	42 optometry students (ages 21–24)	Descriptive (Mean)/ Inferential (*t*-test)	'Optometry Knowledge Challenge' Paper-Based board game	No significant difference in pre-test or post-test scores between lecture and game groups. Post-test scores increased from baseline	Did not explore the effectiveness of the intervention on subgroups defined by academic achievement level or learning style
19	STEM	Students were weak in mastering construction and engineering concepts	Quantitative (Non-experimental)+ Qualitative	Electronically Pre- and post games surveys/focus groups/interviews	21 Year 1 students (age 7)	Descriptive (Frequencies)	Clarkson University's Energy Choices board game: Paper-based	82% of respondents indicated the games had no impact on their desire to remain in their major, although 17% indicated an increase	Only focused on Year 1 students
20	Chemistry (C)	Students found the game mechanics more difficult to grasp than the chemistry material itself	Quantitative (Non-experimental)+ Qualitative	Pre-test and Posttest/ Questionnaire/ Interviews	Students (ages 17–18)	Descriptive (Mean Scores/ Percentages)	Android-system-based Chemistry board Game	The learning result average increased from 34.35 to 80.51.	It focused on the Chemistry subject only
21	Science (S)	Effective assessment strategies are needed to fully capture the potential benefits of technological interventions for large audiences despite the inherent difficulties	Qualitative	Observation	80 junior high school students (11th grade) in Philadelphia (age 15)	Qualitative (Descriptive)	Mobile (Ipad) board game 'Pump that Press!'	Performance is satisfactory for motivated students	The intervention's topic lacked integration with existing curricular activities, potentially affecting student motivation
22	Biofilm formation (B)	No previous study focused on biofilm formation	Qualitative	Checklist/Survey	Young learners (ages 8–12)	Qualitative (descriptive)	Biofilm building paper-based board game	Increased interest, enjoyment, and vocabulary acquisition	Data collection relied on checklists and surveys

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
23	Physics (P)	Some educational games suffer from overly complex rules, making them difficult for players to learn and engage	Quantitative (Experimental)—Quasi-experimental	Pre-test and Posttest	131 students from two high schools in Poland (ages 13–18)	Descriptive (Mean Scores/ SD)/Qualitative (Descriptive)	Physical (paper-based) board games	Improved performance, positive attitudes, and reduced test anxiety	Examined only the short-term effect on students' retention of knowledge
24	Climate change (S)	Secondary school climate change education appears to be insufficient, as students graduate with serious misconceptions	Quantitative	Pre- and postgame surveys	200 students from Germany (ages 10–18)	Inferential (regression)	KEEP COOL paper-based board game	Facilitated experiential learning about climate politics	Did not explore the potential of simulation games for experiential learning in climate change. Specifically, it could have investigated how in-game decisions can influence players' beliefs about climate change politics
25	Virology (B)	Student designers' learning outcomes are not necessarily contingent on the teaching effectiveness of their designs for their peers	Qualitative	Field notes/ Audio recording/ Design artefacts/ Documentation	11 Grade 7 students from the USA (age 13)	Qualitative (descriptive)	Educational board game (card)	Facilitated conceptual change assessment	The conclusions are restricted by its limited sample size and focus on game design abilities without directly assessing scientific understanding of the impact of design. Furthermore, neglecting to consider individual, social, and contextual influences on the science-design interaction limits the comprehensiveness of the research

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
26	Thermal energy (P)	A significant gap between best practices and current approaches in teaching fundamental scientific concepts like thermal energy	Qualitative (Case study)	Rubrics/Paper and pencil test	15 students of 7th grade (age 13)	Descriptive analyses (Mean Scores)	Monopoly-like game	The game successfully promotes qualifying scores for student competencies	Limited participants
27	Nature ecosystems (S)	There is a scarcity of research on designing card game rules and mechanics that are specifically tailored to children's cognitive and developmental abilities	Quantitative (non-experimental)	Photos and Videos/ Questionnaires/ Observations and interviews	Eight kids (ages 11–14)	Descriptive (Mean Scores)/ Qualitative (Descriptive)	Smart Nature Protagonists (SNaP) board game: computer-based	Enabled generating ideas for natural environments	It focused on the board game itself, but a key area for future research is exploring the challenges of translating the ideas generated during gameplay into functional smart objects
28	Chemistry (C)	A passive learning environment can hinder student success in chemistry, a subject that thrives on active engagement and exploration	Quantitative (non-experimental)	Questionnaire	Random sampling/ Five students with a mean age of 12years old	Descriptive analyses (Percentages)	'The Lab City' Board Game: paper- based	Supported better learning compared to traditional methods	While this study explored the potential of board games for learning, it did not delve into more complex subjects like calculus, organic chemistry, quantum physics, or psychology
29	Characteristics of objects (transparent, translucent or opaque) (S)	Misconception of shadow among the students	Quantitative (Non-experimental)	Formative assessment	First and second grade students (ages 6–7)	Descriptive (Percentages)	Shadow Races Game: paper-based with support of other apparatus	Students enjoyed the competition and wanted to play again	It focused on scientific topics and employed traditional learning methods. Future research could explore the potential of inquiry-based board games across various disciplines for a wider range of students

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
30	Environmental sustainability (S)	Addressing the interconnected issues of ecosystem degradation, resource depletion, such as cheap oil, and climate change necessitates a clear roadmap for a sustainable future	Quantitative (Non-experimental)	Surveys	24 undergraduate university students and staff (Ages 21–55)	Descriptive (Percentages)	Computer-assisted board game 'Last Island'	Encouraged cooperative and competitive play in a complex world model	The design process for Last Island could have benefited from additional data collection during workshops. Analysing this data could have provided valuable insights to refine the design further
31	Socio-scientific issues on biological conservation (B)	A key shortcoming of traditional STS education is its failure to bridge the gap between abstract STS concepts and students' personal experiences. This disconnect leads to a decline in student attention and participation	Quantitative/ Qualitative	Questionnaire/ Pretest and Posttest/Semi-structured Interview	38 high-school students (ages 12–16), in Taiwan	Descriptive (Mean Scores/ Percentages)/ Qualitative (Descriptive analysis)	Scientific board game 'Be Blessed Taiwan': paper-based	Increased understanding of biodiversity concepts	The study design did not address the question of how to encourage the widespread adoption of socioscientific board games by science teachers
32	Chemistry (C)	A student's diverse emotions throughout the learning process significantly influence their participation and academic achievement	Quantitative (Experimental)—Quasi-experimental	Pre-test and Posttest/Survey	114 9th graders in Taipei (aged 15)	Descriptive (Mean/ Percentages)/ Inferential (*t*-test/ANOVA/ ANCOVA)	Educational board game: Computer based	Increased positive emotions and decreased negative emotions during learning	Limiting emotional measurement to post-intervention periods overlooks the students' baseline emotional state, which could have influenced their response to the strategies

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
33	Chemistry (C)	The board games prioritise rote memorisation of scientific facts about chemical elements. A more engaging approach would also explore the relevance of these elements in students' daily lives	Quantitative (True experimental)	Pre-test and Posttest/Semi-structured interviews	16 middle school students (ages 14–15)	Descriptive analyses (Mean/SD)/Qualitative (Descriptive)	Scientific board game 'Element Enterprise Tycoon': paper-based (card)	Improved understanding of chemistry concepts and positive attitudes towards science learning	The study did not address teacher motivations for using scientific board games, nor did it involve a large and diverse group of participants across different learning stages, limiting the generalisability of its findings
34	Environmental issues (S)	There is a dearth of empirical research to substantiate the potential of environmental board games as effective educational tools	Qualitative	Focus group interviews	18 respondents (ages 20–29) from Facebook platform	Qualitative (descriptive)	The Settlers of Catan: Oil Springs/ Evolution: Climate/ Global Warming/ Keep Cool Board Games: computer-based	Effective tools for some aspects of environmental communication	Lack of larger-scale quantitative or triangulated methods and potential shortcomings in game design or playtesting evidenced by participants' need for assistance during gameplay, which extended the session lengths
35	Living things and non-living things (S)	Limited studies of multiplayer digital board games for elementary science learning	Qualitative (True-experimental)	Interviews	Six 3rd grade students (ages 8–9) in Thailand	Qualitative (Descriptive)	Multi-player Digital Board Game	Positive student perception towards learning with a digital board game	While the study examined board games for learning, it did not delve into how these games can be effectively integrated with sound pedagogical practices to enhance student achievement

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
36	Environmental issues (S)	There is a significant gap in our understanding of how game design can be leveraged to improve young people's comprehension and communication skills regarding complex systems like ecosystems and human societies	Qualitative	Field notes/recordings/notes and sketches/game artefacts	Two Hispanic and two Caucasian boys (ages 13–17)	Qualitative analyses (Descriptive analysis)	Educational board game: paper-based based (card)	Engaged youth in building models and system thinking	The conclusions are limited in scope as the participants were not chosen to reflect the diversity of the American student population
37	Periodic table (C)	Memorising facts about chemical elements can quickly become a tedious and unengaging task, particularly for younger students	Qualitative	Feedback	Elementary school students and first-year high school students (ages 8–13)	Qualitative (Descriptive)	Chemical Battleship Board Game: paper-based with lab kits	High acceptance and improved knowledge	Only involved the qualitative analyses
38	Physics (Electricity) (P)	Physics is widely perceived as a challenging subject for students at both the high school and college levels	Quantitative (Non-experimental)	Ratings	30 pre-service teachers (ages 20–21) and 10 first year BSED-Physics (ages 17–18)	Descriptive (Mean Scores)	STEM board game Electricladders: paper-based	Excellent tool to demonstrate electricity concepts	
39	Chemical symbol and periodicity of elements (C)	Many secondary school students perceive chemistry as a challenging subject due to its abstract concepts, heavy reliance on mathematics, complex terminology, symbolic nature, and intricate modelling	Quantitative (non-experimental)	Pre-test and Post-test	20 Form IV students (aged 17)	Descriptive (Test Scores)	Symperiod Board Game: computer-based	Effective for learning periodicity	Limited participants

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
40	Biological conservation (B)	Science and environmental education often prioritise rote memorisation of facts, neglecting opportunities to foster deeper understanding and critical thinking skills	Quantitative (Non-experimental)	Tests/Interviews	34 high school students (ages 13–18)	Descriptive analyses (scores)	'Be Blessed Taiwan': paper-based	Increased student test scores on biodiversity and biological conservation concepts	Focused on a single board game theme, limiting its exploration of how diverse board game themes could be used to simulate various scenarios and enhance ESD teaching
41	Global change (S)	Public understanding of environmental threats is increasing, but a wide gap persists between stated beliefs and the actions of a large portion of the population	Quantitative (non-experimental)	Pre-test and Posttest/Survey	Six Master's students (ages 26–28) and 128 Bachelor's students	Descriptive (Scores)	Educational board game: paper-based	Promoted a sense of personal environmental responsibility and aligned with engagement in climate change issues	This small-scale, short-term study's limitations include low response rates for specific student behaviours and a lack of investigation into key GC components like biogeochemical cycles and land use changes. Future research with a larger sample size and a broader scope could provide more comprehensive insights
42	Food and nutrition (S)	Despite the abundance of board games available, few are designed with educational principles in mind, limiting their effectiveness as classroom teaching tools	Quantitative (True experimental)	Pre-test and post-test/ Questionnaires/ Interviews	22 middle school students in Grade 7 in Beijing (aged 13)	Descriptive (Scores)/ Qualitative (Descriptive)	Nutrition educational board game: paper- based	Increased knowledge, positive attitude shifts, and behavioural changes, particularly among females and students with abnormal BMI	The generalisability is limited due to the small sample size, and only sixweeks may not be sufficient to observe significant and lasting changes in attitudes and behaviours

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/ population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
43	Water cycle (S)	While the use of serious games for informing stakeholders is well-established, their potential as engaging and effective teaching tools remains under-explored in this study	Quantitative (Non-experimental)	Observations/ Interviews/ Questionnaires	51 people from seven communities (ages 21–55)	Descriptive (Frequencies)/ Qualitative (Descriptive)	Educational board game 'Sui-Maru': paper- based	Potential as an effective tool for promoting sustainable water management	The board game did not prioritise conveying educational messages about water cycles and water-related issues, limiting its potential as a learning tool
44	Biology (B)	Finding a way to teach students about COVID-19 clearly and engagingly proved to be a significant challenge	Quantitative (Non-experimental)	Pre-test and Posttest survey	High school students (multiple schools)—K-12 students (ages 5–18)	Descriptive (percentages)	Online and electronic board game 'Attack Covid Game): digital board games	Enjoyed by students, with plans to develop a wider electronic distribution	Limited resources, time, assets and efforts in this study
45	Physics and Astronomy (P)	Educators' limited experience and knowledge of Game-Based Learning methodology may be a significant barrier to its wider adoption in the classroom	Quantitative and Qualitative	Questionnaires/ Systematic observations/ Pre-test and Posttest surveys/ Focus group with students	119 post-primary students in Ireland (ages 7–12)	Descriptive (Mean scores/ SD)/Inferential (*t*-test/ANOVA)	Novel astronomy board game: paper-based- (card)	Enhanced astronomy knowledge, perception of scientists, and potential for physics education using game-based approaches	The study design limits the ability to conclude the long-term effectiveness of the intervention due to the lack of a retention evaluation
46	Natural science (S)	The School of Education currently lacks research on how pre-service natural science teachers experience the development of educational science board games	Qualitative (Case study)	Focus group discussion/ Photo-voice methodology	Pre-service teachers at a South African university (age 24)	Qualitative (Descriptive)	Educational Science board games: paper-based	The development of science board games positively impacted pre-service teachers' skills, professional development, and pedagogical content knowledge	Only focused on science education applications of board games. Future research could explore how this approach can be adapted to other subject areas, such as mathematics, technology, and social studies

ID.	Main subject P-physics B-biology C-chemistry S-science	Issues addressed	Method	Collection	Sampling methods/population/sample sizes/age	Data analysis	Board game types	Findings	Limitations
47	Digestive system (S)	Traditional media may fail to capture students' attention, hindering their comprehension of the material and ultimately leading to lower learning outcomes	Quantitative (Non-experimental)	Questionnaires	Grade VIII students (age 14)	Descriptive (Scores)	Sciencemopoly Game: paper-based	Valid and effective for teaching the digestive system	Only focused on the students' learning motivation
48	STEM Education	The influence of Game-Based Learning on problem-solving skills remains limited	Quantitative (True-experimental)/ Qualitative (Case study)	Pre-test and Posttest/Case study	90 lower secondary students (ages 13–15)	Descriptive (Mean Scores/ SD)/Inferential (*t*-test/ Descriptive)	Board Game-based Learning (Yes/ No Organ, Control Wave Sample, P.W. Mastery): paper-based	Increased problem-solving skills and positive learning experiences, with mixed results on self-efficacy	Although limited to the direct impact of Game-Based Learning, this study provides a foundation for further research that explores additional factors contributing to the development of problem-solving competencies
49	Physics (Waves) (P)	Students struggle most with abstract topics that lack concrete examples and rely heavily on symbolic representations. These subjects often necessitate advanced mathematical manipulations, visualisation, or conceptualisation skills	Quantitative and Qualitative	Curriculum Guide/ Rubric	Grade 7 students (age 13)	Quantitative (Average ratings)/ Qualitative (Descriptive)	STEM board game: paper-based	Interesting and considered a useful tool for learning about waves and promoting STEM education, with suggestions for improvement	Only focused on waves for Grade 7 students
50	Organic chemical structure and functional groups (C)	Learning organic chemistry concepts can be challenging due to its abstract and complex nature	Quantitative (True experimental)	Pre-test and Posttest	151 high school students in northern Taiwan (ages 15–18)	Descriptive (Mean Scores/ SD)/Inferential (*t*-test/ANCOVA)	Educational board game: Digital-based	It is more effective than traditional lectures for understanding organic chemical structures and functional groups	Did not apply CSLS model to different learning subjects

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51	Ecosystem (S)	Developing engaging and effective educational digital games requires overcoming hurdles, balancing educational goals with entertainment value and ensuring technical compatibility with the classroom	Quantitative (Non-experimental)	Pre-test and Posttest/Surveys	37 junior high school students in northern Taiwan (ages 12–15)	Descriptive (Mean Scores/ SD)	Educational Board Game with Augmented Reality 'Ecological Restoration': digital-based	Improved understanding of ecosystem concepts and perceived as useful and easy to use	This study is still in the preliminary phase, as other learning subjects are not involved
52	Human internal organs (B)	Health and physical education are not major academic disciplines in elementary school, like science, technology, engineering, and mathematics	Quantitative (true experimental)	Pre-test and Posttest	74 elementary 4th-grade students (aged 10)	Descriptive (Mean Scores/ SD)/Inferential (ANCOVA)	3D electronic board game 'Organ Saviour Game': Digital-based	Significantly improved learning achievements compared to a conventional board game	Only focused on the integration of board games into computer software to enhance student's learning effectiveness in the health and physical course
53	Nature environments (S)	Fewer resources for collaborative board games in learning smart nature environments	Qualitative	Indirect observations/ Interviews/ Questionnaires	Four 11-year-old children	Descriptive (Scores)/ Qualitative (Descriptive)	'SNaP 'Collaborative board game: Digital-based	Structures children's ideas and promotes shared reflections on nature environments	Only focused on the game's impact on learning outcomes, with less emphasis on the game experience itself. Future research could benefit from using additional assessment tools to explore players' enjoyment and satisfaction with the game
54	Diseases (taeniasis) (B)	No previous educational outreach events about taeniasis have been conducted in schools located in the Banjar of Pandan	Quantitative (true experimental)	Pre-test and Posttest	78 children (ages 9–12)	Descriptive (Scores/ Percentages)	'Snakes and Ladders' board game: paper-based	Increased knowledge about taeniasis, but not significant for the youngest age group	Did not include control populations to assess learning outcomes better

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55	Chemistry (C)	Low level of scientific concepts and creative problem-solving skills among the students	Quantitative (true experimental)	Pre-test and Posttest/Interviews/CPS skills test	48 high school students (ages 16–17) in northern Taiwan	Descriptive (Scores/Mean/SD)/Qualitative (Descriptive)	Scientific board game 'Element Enterprise Tycoon': paper-based (card)	Improved scientific concepts, problem-solving skills (solution-finding), and overall view of chemistry's function	The time commitment required for playing board games can be a drawback, and the identical pre- and post-test scenarios raise concerns about the potential for an 'exposure effect' influencing the results, where simply being exposed to the material, regardless of learning, might impact performance
56	Public Health Biology (B)	Students struggle to understand and apply biology concepts, and traditional lectures may not accurately represent the complexity of real-life situations or learning in practice	Quantitative and Qualitative	Pre-test and Post-test/Focus Groups/Interviews	151 University students in Toronto (ages 18–22)	Quantitative (Pre- and post-test scores/ANOVA)/Qualitative (Descriptive)	The Bioracer Board Game: paper-based	Slightly improved knowledge gain and found helpful for learning course content	Due to time constraints, it focused primarily on assessing knowledge and understanding. However, a more comprehensive evaluation would have included students' biological content knowledge before and after the intervention. Additionally, the single intervention with a limited timeframe makes it difficult to determine if the observed effects are long-lasting or reproducible

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57	Osmolarity and Tonocity (B)	The complexity of the concepts of osmolarity and tonicity lead to misunderstandings among the students	Quantitative	Questionnaire	73 dental students (2019), 25 & 43 dental/mental students (2022)	Quantitative analyses	Educational board game: paper-based	Students believed the game improved understanding, interaction, and perception of learning	The data collected from a survey administered in 2022
58	Elements of the periodic table from H to NO. (C)	A direct translation of the questions was not possible due to specific cultural references, which would not make sense in translation for a chemistry subject	Qualitative	Observations	Young students (ages 14–18) in 24 classes	Qualitative	Chemical Quest Board Game: paper-based	Adaptable to different educational objectives	Only involved 24 upper secondary school students playing board games
59	Mole Calculation skills and understanding (C)	Limited studies of mole conversion	Quantitative	Pre-test and Post-test/Survey Questionnaire	29 grade 10 students (age 16)	Quantitative	Educational Board Game: paper-based	Promoted active learning, engagement, and understanding of mole calculations	Only focused on mole calculation topics
60	Chemical Reactivity (C)	Bridging the gap between understanding representations and applying them to solve problems is a significant challenge for both instructors (to teach) and students (to learn)	Quantitative	The electronic form contains seven statements with responses based on a Likert-type scale	42 pharmacy and chemistry students in Brazil (ages 21–23)	Quantitative	CR322 Web-Based Board Game	Students positively evaluated the game as an alternative to traditional learning methods for chemical reactivity	It focused solely on a digital version of the game, neglecting to explore the potential benefits of a hybrid design that caters to players who enjoy the physical aspects of traditional board games, such as handling the components and social interaction

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61	Pedagogical Content Knowledge (Science) (S)	The impact of developing educational science board games on preservice teachers' demonstration of pedagogical content knowledge remains largely unexplored	Qualitative	Focus group discussion and photo-voice methodology	Pre-service teachers (Ages 19–22)	Qualitative	Educational Science Board Games: paper-based	Enabled pre-service teachers to demonstrate science-specific assessment knowledge	It focused on how pre-service science teachers perceive the development of educational board games, neglecting to explore 1) their experiences using these games in actual teaching and 2) the potential application of this approach to other STEM subjects like mathematics, technology, and physical science
62	Science (S)	Learning the concepts of astronomy demands abstraction capabilities, but this is challenging for middle-grade students	Qualitative	Written responses	60 middle school students (Ages 13–17)	Qualitative	'I arrived at the Sun!' Board Game: paper-based	Students found the game enjoyable and effective for learning science	Did not develop different educational games in various subjects for teaching and learning science
63	Oral Health Education (B)	While lectures, demonstrations, and simulations can increase children's knowledge of oral health, these methods fail to translate that knowledge into lasting behavioural changes	Qualitative	Interview and Observation	44 school children (aged 12)	Qualitative	ToothPoly Board Games: paper-based	Children perceived ToothPoly as a useful, interactive, and enjoyable tool for learning about oral health	The sample size was limited by the differing school reopening schedules following the COVID-19 outbreak, which restricted participation from a wider range of schools

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64	Geotechnical Soil Characterisation (S)	Limited access to equipment hinders students' ability to gain hands-on experience with geotechnical testing methods. Understanding these methods' limitations and challenges is essential for the proper interpretation of geotechnical data	Quantitative	Questionnaire	Eight civil engineering undergraduate students (ages 8–22)	Quantitative	'Soil Character' Board Game: computer-based	Suggested that gamification can make geotechnical engineering more engaging	Did not involve the application of board games as supplementary teaching tools in soil mechanics courses or their adaptation to other fields of engineering and science that involve complex concepts and terminology
65	Quantum science (P)	The challenge lies in making quantum concepts accessible and engaging to younger students	Qualitative	Open-ended surveys, field notes, workshop artefacts and interviews	Seventy K-12 teachers (ages 22–55)	Qualitative	Educational Board Game: paper-based	Increased teacher enthusiasm for teaching quantum concepts	Current systemic constraints on teachers, including overloaded curricula and a lack of time for 'extra topics,' may restrict the effective integration of quantum concepts into the K-12 curriculum
66	Cell Division (B)	Misconceptions about cell division impact students' understanding of more complex life processes, such as reproduction, growth and genetic inheritance	Quantitative	Pre-test and post-test	61 secondary schools students (ages 13–17)	Quantitative (mean scores)	BioBoard-G Board Game: paper-based	Students exposed to BioBoard-G showed significantly higher knowledge gains than those exposed to online gamification	Only focused on a single-board game design

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67	Biochemistry (Vitamins) (B)	The complexity of biochemistry can be particularly challenging for students to grasp when presented solely through lectures. This passive learning approach can hinder active engagement, making it difficult for them to absorb the material effectively	Quantitative	Questionnaire	24 medical students (ages 22–24)	Quantitative analyses (percentages)	CARDGAME (Card & Board Games in Medical Education): paper-based	All students found CARBGAME to be a rewarding and engaging learning experience	Only a questionnaire was used to collect the data without investigating the effectiveness through pre-tests and post-tests
68	Climate Literacy and Environmental Literacy (S)	The children exhibited difficulties differentiating between the causes and consequences of climate change. Additionally, they demonstrated a lack of understanding regarding the concept of the ecological footprint	Qualitative	Focus groups	54 children (ages 9–13) from Portugal	Qualitative (content analysis)	'Climate Action' Board Game: paper-based	Children gained a better understanding of climate change and its causes, consequences, and solutions and felt motivated to help	Only involved the use of focus groups to collect data
69	STEM	Children are unable to master STEM language for life-size math and science	Qualitative	Observation	562 groups/families with children (ages 25–55)	Qualitative	'Parkopolis' Board Game: paper-based	Caregivers and children showed increased STEM language, engagement, interaction, and physical activity compared to a traditional STEM exhibit	This study design might have introduced bias because the observers, though unaware of the specific hypotheses, were aware of the condition (intervention vs. control group). Additionally, estimating participants' age and gender could have influenced their observations

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70	Fossilisation and Earth Systems (S)	Low level of students' behaviour in learning outcome of fossilisation and Earth systems	Quantitative	Questionnaire	49 high school students (12th-grade) in Texas (age 18)	Quantitative	'Taphonomy: Dead and Fossilised' Board Game: paper-based	Increased ability to apply paleontological knowledge to Earth systems thinking	Time constraints limited the implementation of more comprehensive evaluation protocols. Additionally, the study did not employ pre-tests and post-tests to distinguish between knowledge gained through gameplay and prior knowledge
71	Marine Environment and Ocean Awareness (S)	Game-based learning leads to difficulties in time management, and players feel frustrated if they do not complete the game	Qualitative	Participant observation	222 players (111 children aged 11–15 and 111 adults aged 18–72)	Qualitative	'The Game of the Sea' Board Game: paper-based	Increased knowledge of the marine environment for both children and adults	Only involved qualitative analyses
72	Chemistry (C)	A critical gap exists in our understanding of the long-term effectiveness of educational games and their impact on students with diverse learning styles and abilities	Quantitative	Conceptual test and survey	114 high school students in Taipei (9th graders, age 16)	Quantitative	Educational Board Game: computer- based	Increased positive emotions and decreased negative emotions during learning	Only involved quantitative analyses

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73	STEM	Students' poor cognitive development is associated with a lack of interest in learning chemistry, motivation to persist in mastering complex chemistry concepts, and inadequate instructional approaches to chemistry education	Mixed mode	Diagnostic test, Observation	214 (Students' ages 7–12, Caregivers' ages 25–55)	Quantitative and qualitative	Parkopolis—Life-Sized Board Game: paper-based	Created an environment for adult–child interaction and support	This study measured students' emotions after exposure to innovative and conventional teaching strategies each week. It did not assess their pre-existing emotional states, making it difficult to determine the full impact of the strategies on their emotional engagement. Additionally, achieving high cognitive objectives (complex learning goals) might require more class time and exploration of diverse teaching designs beyond those compared in this study
74	Marine Science (S)	Many teachers have shifted from traditional, lecture-based methods to adopting a more dynamic approach. They now incorporate innovative tools and customise instruction to meet the specific needs of their students	Quantitative	Pre-test and post-test questionnaire	51 school students in Taipei City (ages 13–17)	Quantitative	Marine Science Board Game: paper-based	Increased scores on a marine science inventory and self-reported confidence	Did not focus on using board games to enhance learning motivation and interest
75	Organic Chemistry (C)	Complex concepts and large amounts of material cause undergraduates to face difficulties in mastering knowledge	Quantitative	Questionnaire	103 university and high school students (ages 19–21)	Quantitative	European-style Board Game: paper-based	Stimulated critical thinking about organic chemistry concepts	Does not involve the application of performance test results

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76	Environmental Chemistry (C)	Students are initially introduced to the concepts of essential elements in grades 4–6, but they do not usually study them intensively until secondary environmental science classes	Quantitative	Pre-test and post-test	95 high school students (ages 13–17)	Quantitative (scores)	'Element Cycles' Board Game: paper-based	Improved post-test scores for Pre-AP chemistry students	Did not include the use of qualitative analyses to collect data