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A systematic literature review of STEM learning using games in elementary education

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Abstract

This systematic review aims to synthesize recent research and propose essential recommendations on using games in science, technology, engineering, and mathematics (STEM) education at the elementary school level ages 6-12. A comprehensive literature review was conducted using the Scopus database and the PRISMA framework. Based on 177 studies from 2015 to June 2025 in the initial Scopus search records, using the PRISMA framework, 27 articles were identified that focused on using games in STEM education at the elementary school level. Data extraction included research methods, theories, types of games, potential effects, and reported factors. The findings reveal a methodological diversity dominated by mixed-methods, reflecting a theoretical shift toward neo-Piagetian, social constructivism, and experiential learning that emphasizes active knowledge construction. This theoretical foundation is operationalized through digital platforms utilizing narrative and exploration-based mechanics, which prioritize pedagogical alignment and learner engagement over simple rewards. Consequently, while increased motivation remains the most frequent impact, these pedagogically aligned designs uniquely facilitate the emerging and significant outcome of shaping students' STEM identities from an early age.

Keywords: game, elementary schools, PRISMA guidelines, STEM education

INTRODUCTION

STEM is an educational approach and a collective term that integrates four specific disciplines: science, technology, engineering, and mathematics. STEM is more than a group of school subjects; it is a strategic and integrative educational approach designed to equip students with the tools to analyze, innovate, and lead in a rapidly changing world. Its emphasis on real-world problem-solving, interdisciplinary knowledge, and critical thinking makes it essential for education systems worldwide (King & English, 2016). The urgency of implementing STEM at the elementary level lies in its pivotal role in shaping foundational knowledge, preventing the development of persistent achievement gaps, fostering inclusive opportunities, and igniting a lifelong interest and confidence in STEM. Failing to address STEM education early risks perpetuating inequities (Cohen et al., 2021), undermining economic progress, and leaving students unprepared for the demands of a technologically advanced society (Repenning et al., 2015). Early, effective, and engaging STEM education is both an individual and societal imperative. Games provide interactive environments where students learn by doing, experimenting, and problem-solving. Instead of passively receiving information, students actively manipulate the variables, make decisions, and see immediate consequences, which deepens their conceptual understanding in STEM subjects (Van Eck et al., 2015).

The use of games in STEM learning has increased over the past 10 years. A wealth of recent research has provided insight into the growing knowledge base of games and STEM learning (**Table 1**).

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Contribution to the literature

- The results of this study propose a new model or framework for integrating games into STEM education that is effective, particularly one that is appropriate for the characteristics and developmental levels of elementary school students.
- This new model or framework is essential to avoid the risk of failure when integrating games and STEM education.
- While integrating games into STEM education may seem enjoyable and engaging for students, if the implementation is too complex, it risks further diminishing their interest in actively participating and learning. It is crucial to uncover the effectiveness of games integrated into STEM education and the factors influencing it through an SLR.

Table 1. Literature of previous reviews

Article	Year	RT	Coverage	N	Database referred
Tene et al. (2025)	2025	SLR	2010-2023	37	Scopus, Web of Science, PubMed, and IEEE Xplore
Kefalis et al. (2025)	2024	SLR	2019–2024	31	ERIC, Scopus, and Web of Science
Kustiyarto and Marhaeni (2025)	2024	SLR	2016-2024	21	Google Scholar
Yu et al. (2022)	2022	SLR	2011-2020	46	Unknown or not detailed in the abstract
Vásquez-Carbonell (2022)	2022	SLR	2017-2021	58	Science-Direct and IEEE
Gao et al. (2020)	2020	SLR	2010-2019	30	ERIC, SpringerLink, Wiley Online Library, and JSTOR

Note. RT: Review type; N: Number of reviewed studies

Through systematic literature review (SLR), Tene et al. (2025) investigated the effectiveness of serious games for improving learning outcomes, engagement, and STEM performance. The findings show positive impacts, but technical challenges, the need for teacher training, and data privacy issues exist. Carefully selected research studies published between 2019 and 2024 (Kefalis et al., 2025) showed that interactive simulations were the most widely used, with quasi-experimental designs and inquiry approaches being dominant. Digital simulations are practical, but elementary and special educational research is lacking. Kustiyarto and Marheni (2025) conducted a SLR. They found that creating educational games has been shown to contribute positively to strengthening students' understanding of mathematical concepts and improving their digital literacy skills. However, this study is still limited to the Google Scholar database and only highlights the subject of mathematics out of STEM. Forty-six relevant studies were selected to provide insights into its contribution (Yu et al., 2022). The study shows that marker-based games with puzzle elements dominate augmented reality (AR) digital game-based learning (GBL) but many game elements are not fully utilized. Mathematics is the most popular, and location AR shows more elements. Vásquez-Carbonell (2022) studied the various trends present in STEM games using the ScienceDirect and IEEE databases. Their study found a trend in AR software development regarding engineering students, led by Germany and India. Unity and smartphones are dominantly used, focusing on increasing student learning motivation. Another SLR study was done by Gao et al. (2020); their analysis was conducted on the context, focus, methods, and features of mobile games in STEM learning. The review highlights the need for further research to determine when this approach is appropriate. However, this study only focuses on engineering education, which is part of the STEM subject. Therefore, This study analyzes explicitly the methodological approaches used in related studies, the theoretical models underlying the development of the educational games, platforms, and applications used, the most common game mechanics found, the educational impact of implementing games in STEM learning in elementary schools, and the characteristic factors that influence the success of their implementation.

In addition, beyond general analyses of games and STEM, specific studies have begun exploring the impact of games on student skills. For instance, a review by Pum et al. (2025) identified correlations between gamification and the development of collaboration, critical thinking, problem-solving, and digital literacy. However, this particular review faces significant methodological limitations that undermine its rigor and generalizability. The lack of transparency in the screening process and the absence of a PRISMA flow diagram hinder replicability, while the absence of deep contextual analysis regarding different education levels limits the understanding of optimal implementation. To address the specific gaps identified in the work of Pum et al. (2025), our study strictly adheres to the PRISMA guidelines to ensure a fully transparent, structured, and replicable selection process. Moreover, this study is exclusively focused on the elementary school context (ages 6-12), providing the contextual mapping that previous analyses lacked. Furthermore, by utilizing the Scopus database, this study ensures that the synthesis is built upon high-quality, peer-reviewed publications, thereby offering a more credible and rigorous foundation for understanding STEM games in early education

This SLR on games in STEM education is a broad term encompassing a wide spectrum of interactions between games and instruction. Using the single keyword "game" in the literature search process risks producing overly generalized findings or a mix of purely entertainment articles. Therefore, this study used three key technical terms to ensure comprehensive terminology and avoid missing relevant articles, whether that was discussing educational games as products, games as teaching methods, or the use of game elements and learning settings. To maintain consistency in the data selection and extraction process, this study defines these three concepts as follows:

1. Educational games refers to research on content design in which games are created as a unified whole, specifically designed with instructional goals in mind (De Freitas, 2018; Tejada-Simon, 2024). In the context of data extraction, this category identifies products that organically integrate pedagogical and entertainment content through game simulations or narratives.
2. GBL is defined as an instructional approach using complete games (either digital or non-digital) as the primary instructional activity in structured learning sessions (Coelho et al., 2025; Coleman & Money, 2020). The difference lies in the use of gameplay as a medium to achieve predetermined learning and assessment objectives.
3. Gamification emphasizes the application of game design elements, such as points, badges, and leaderboards, into non-game learning environments, in this case, learning (Coelho et al., 2025).

This study presents a sharp, relevant, and credible synthesis by focusing on the context of elementary education and using sources only from Scopus. Unlike previous literature reviews that are more general in nature, this study makes an important contribution to developing a more holistic understanding of educational games in elementary STEM education. The findings are expected to be a strong foundation for formulating educational policies, instructional design, and contextual and directed research. The research questions (RQs) in this study include the following:

RQ1. What methodological approaches have been used in research related to educational games for STEM learning in elementary schools?;

RQ2. What underlying theoretical models are used in educational games for STEM learning in elementary school research?;

RQ3. What platforms/applications and common game mechanics have been used in educational games for STEM learning in elementary school research?;

RQ4. What are the educational effects due to implementing educational games for STEM learning in elementary schools?; and

RQ5. What characteristic factors affect implementing educational games for STEM learning in elementary schools?

This SLR was guided by a descriptive synthesis approach driven by the RQs. Specifically, **RQ2** addresses the theoretical foundations of the reviewed studies by systematically identifying and categorizing the underlying theoretical models adopted in research on educational games for STEM learning in elementary schools, thus enabling the synthesis to reflect the theoretical diversity emerging from the studies analyzed in this SLR.

METHODOLOGY

The database chosen to provide a strong basis for this evaluation was Scopus, which gives access to high-impact journals in the STEM domain. This database is used in the search strategy to look for research pertinent to STEM education, specifically gaming, in elementary schools. To guarantee that contemporary developments in gaming and its applications in STEM education are included, this review concentrates on studies published within the last 10 years (2015-2025). The quick growth of instructional resources and techniques corresponds with this period. A transparent and systematic review process was ensured by adhering to the PRISMA methodology. The PRISMA criteria offers a methodical way to record every phase of the research selection process, from identification to screening and eventual inclusion. A comprehensive set of search phrases and screening standards tailored to each database was first developed to identify studies that best addressed the RQ. The search query for Scopus was as follows: ("STEM" OR "Science, technology, engineering, and mathematics") AND ("GAME" OR "GAME-BASED LEARNING" OR "GAMIFICATION") AND ("ELEMENTARY SCHOOL" OR "ELEMENTARY" OR "PRIMARY SCHOOL"). Filters included peer-reviewed journal articles published in the last 10 years. The inclusion and exclusion criteria are presented in **Table 2**.

To ensure the full methodological transparency of the review process, this section provides a detailed explanation of the inclusion and exclusion criteria, along with a step-by-step description of the manual screening procedures applied to determine the final set of included studies. Initially, 177 articles were retrieved from the Scopus database. The dataset was refined by applying a publication date filter limited to the last 10 years, excluding 13 articles, resulting in a final 164 articles. Further filters were applied to include only peer-reviewed journal articles written in English, excluding review papers and conference proceedings.

Table 2. Inclusion and exclusion criteria applied in the SLR

No	Inclusion criteria	Exclusion criteria
1	Studies published between 2015 and June 2025	Studies published before 2015
2	Studies published in peer-reviewed journals	Non-peer-reviewed publications (reviews, conference papers, and opinion articles)
3	Studies written in English	Non-English publications
4	Empirical studies	Non-empirical studies
5	Studies focusing on STEM education involving games or gamification	Studies not related to STEM, not involving games and gamification, or that were not conducted in elementary school settings

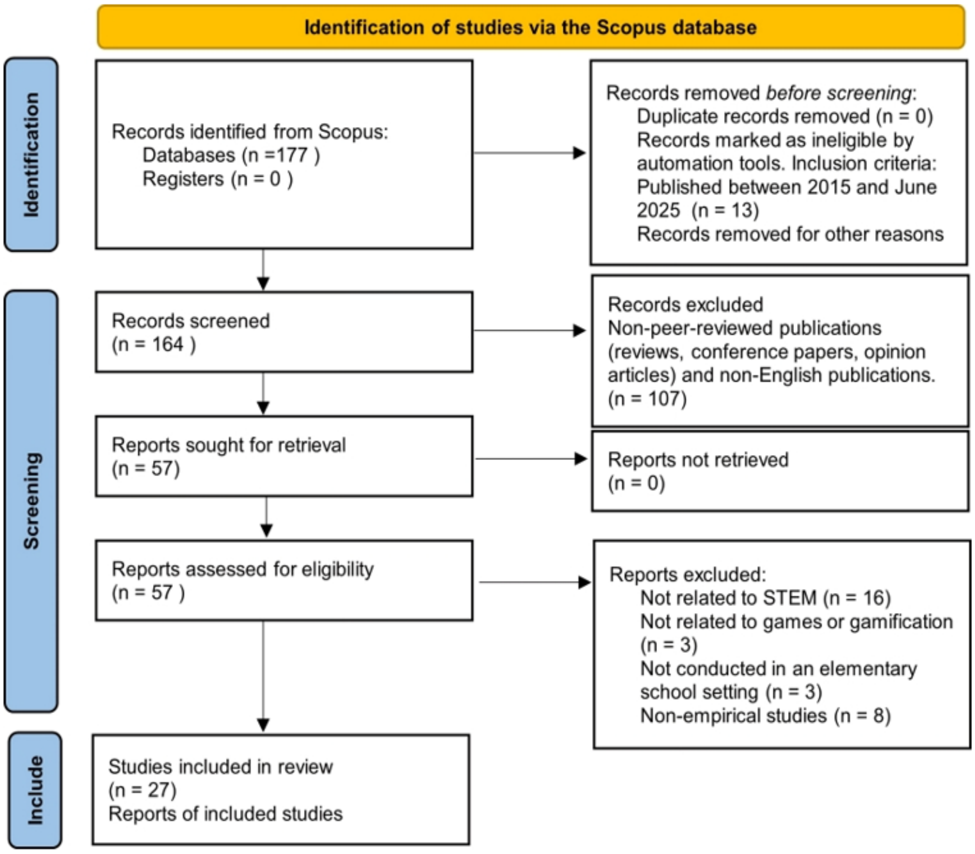

Figure 1. PRISMA flow diagram (Source: Authors' own elaboration)

This automated filtering process excluded 107 articles, leaving 57 articles retained for title and abstract screening. A manual screening process was then conducted based on the predetermined inclusion and exclusion criteria of "studies not related to STEM", "not involving games, gamification", "not conducted in elementary school settings", or studies that were "non-empirical" in nature. During this stage, 30 studies were excluded for the following reasons: 3 studies were not related to GBL or gamification; 16 studies were not focused on STEM education; 3 studies were not conducted at the elementary school level; and 8 studies were excluded because they were not empirical research. As a result of this multi-stage screening and eligibility assessment process, 27 studies were deemed eligible and were included in the final analysis.

This procedure is depicted in the PRISMA flowchart (Page et al., 2021) in **Figure 1**, which includes information on the initial number of publications found during the database search, according to the exclusion criteria, and the final set of 27 studies.

The data extraction and coding process was conducted by our team of six researchers using a data-driven approach. Information was recorded exactly as explicitly reported in each primary study, ensuring that no predetermined analytical categories were imposed during the initial extraction phase. An exception was made for the analysis of **RQ3**, where game mechanics were deductively identified and categorized based on the taxonomy developed by Arnab et al. (2015). After extraction, the identified data was coded descriptively and grouped to support comparison and synthesis across the studies. It is worth noting that the review process consisted of several stages. Firstly, a table consisting of several columns was developed to record

(1) the title of the article and the author(s) of the article being reviewed,

Table 3. Distribution of empirical research methodologies in elementary school STEM game studies

Research method category	Article references	F
Experimental/quasi-experimental designs	Juric et al. (2018, 2021), Mawas et al. (2020), Puig et al. (2022), Rossano et al. (2020), Rowe et al. (2021)	6
Mixed-methods (quantitative & qualitative)	Burušić et al. (2021), Hunt et al. (2023a, 2023b), Marks et al. (2021), Slattery et al. (2024), Van Eck et al. (2015)	6
Survey/questionnaire-based (cross-sectional, descriptive or correlational)	Ball et al. (2020a, 2020b), Bofferding et al. (2022), Cohen et al. (2021), Vate-U-Lan (2015)	5
Case study/qualitative	Botes (2024), Mildenhall et al. (2021), Nang and Harfield (2018), Orak et al. (2020), Yllana-Prieto et al. (2023)	5
Design-based/development & evaluation cycles	Hunt et al. (2022), Mullin and Milburn (2021), Podpečan (2023), Ramli et al. (2021), Repenning et al. (2015)	5

Note. F: Frequency

(2) the methods used (for example, experimental/quasi-experimental designs, mixed-methods (quantitative & qualitative), survey/questionnaire-based (cross-sectional, descriptive, or correlational), case study/qualitative, and design-based/development & evaluation cycles),

(3) the theoretical models used (for example, Piaget's, Vygotsky's, ZPD, collaborative learning, ARCS model, MDA, etc.),

(4) the platforms/applications and the most common game mechanics used,

(5) educational effects, and

(6) the factors that affect implementing educational games.

Secondly, before filling in the data columns, all selected articles were reviewed and the relevant information was entered into the table by the first researcher. Third, to test the suitability and consistency of the review process carried out by the first researcher, the same articles were reviewed by the second to sixth researchers. Fourth, a face-to-face meeting was held by the first to sixth researchers to discuss and compare the results of the keyword table entries that would be included on the main sheet. Fifth, after reaching a shared understanding, the columns in the table on the main sheet were filled in based on the alignment of perceptions agreed upon by the six researchers.

This process was repeated until consensus was reached for all review results. Data analysis was conducted systematically to answer the five RQs. For all RQs, the data sources were analyzed through frequency and percentage calculations using Microsoft Excel. The absence of statistical interrater reliability measures (e.g., Cohen's kappa) is acknowledged as a potential limitation regarding coding objectivity.

RESULTS

The findings were obtained from analyzing the 27 selected documents extracted from the Scopus database based on the inclusion criteria applied in the PRISMA flow. The study of the results of the systematic review revealed the methodological approaches used, as well as the theoretical focus, platforms, and game mechanics often used in research on the use of games in STEM learning in elementary schools, including their potential impact and the characteristics of the influencing factors.

Methodological Approach to the Research on Gamified STEM Learning in Elementary Schools

The SLR results show a fairly diverse distribution of research methodologies in the literature reviewed (**Table 3**). Of the total 27 articles analyzed, the mixed-methods methodology (quantitative and qualitative) dominates with the highest frequency of 6 articles (22.22%), which shows the tendency of researchers to use a comprehensive approach when exploring the research phenomena. Experimental/quasi-experimental designs have the same frequency, namely 6 articles (22.22%). This indicates that experimental approaches make up a significant portion of the studies reviewed, especially intervention testing and product/system development.

Survey-based quantitative studies (including cross-sectional, descriptive, and correlational designs), qualitative case study research, and design-based or development-and-evaluation cycle methodologies show identical frequencies of 5 articles (18.52%) for each category. This distribution illustrates a balanced use of descriptive-correlational quantitative approaches, in-depth qualitative inquiry, and iterative development-oriented research in the analyzed literature. The diversity of research methodologies reflects the complexity of the topics studied and shows that no one methodological approach is dominant. This result shows that research in this domain requires various methodological techniques to understand phenomenon comprehensively from multiple perspectives.

Theoretical Models and Frameworks in STEM Gamification Research in Elementary Schools

Studies that have addressed STEM learning using games in elementary schools have found that various theoretical models and frameworks have been used to guide the design, implementation, and evaluation of interventions (**Table 4**). These models provide a

Table 4. Distribution of the use of specific models, theories, and frameworks in the elementary school STEM game literature

Specific model/theory/framework	Representative articles
Piaget's constructivism and situated learning	Juric et al. (2021), Rossano et al. (2020), Van Eck et al. (2015)
Neo-Piagetian theory (case, learning trajectories)	Bofferding et al. (2022), Hunt et al. (2022, 2023a), Puig et al. (2022)
Social constructivism (Vygotsky, ZPD, collaborative learning)	Burušić et al. (2021), Juric et al. (2018), Mildenhall et al. (2021), Repenning et al. (2015)
Self-determination theory	Orak et al. (2020)
ARCS model (attention, relevance, confidence, satisfaction)	Marks et al. (2021)
Gamification as educational model (mechanics-dynamics-aesthetics, LEGA)	Mawas et al. (2020), Puig et al. (2022), Yllana-Prieto et al. (2023)
Four-dimensional framework	Nang and Harfield (2018)
GBL theory	Mawas et al. (2020), Slattery et al. (2024), Vate-U-Lan (2015)
Human-centered design approach	Rossano et al. (2020)
Computational thinking	Repenning et al. (2015), Rowe et al. (2021)
Pedagogical content knowledge	Botes (2024)
UDL	Hunt et al. (2022, 2023a, 2023b)
Experiential learning theory, inquiry-based/problem/project-based learning	Mawas et al. (2020), Mullin and Milburn (2021), Orak et al. (2020), Puig et al. (2022),
Outcome-based education/backwards design	Puig et al. (2022)
Social cognitive theory (self-efficacy)	Ball et al. (2020a, 2020b)
Science capital theory	Cohen et al. (2021)
Cognitive theory of multimedia learning	Ramli et al. (2021)
Not available	Podpečan (2023)

conceptual foundation and help researchers understand how the use of games can impact student engagement, learning outcomes, and STEM identity development. The diversity of theories used reflects the complexity of the phenomena studied and the interdisciplinary approach inherent in these studies.

Several theories and frameworks show a higher frequency of use, each appearing in 4 articles (14.81%). Neo-Piaget theory, social constructivism, and experiential learning theory/inquiry-based learning each showed significant use in the reviewed literature. GBL theory, gamification as an educational model, and the universal design for learning (UDL) also showed consistent use, each appearing in 3 articles, reflecting the trend of using GBL approaches in recent research. Piaget's constructivism theory and situated learning are the most frequently used theoretical bases, appearing in 3 articles (11.11 %). This result indicates that the constructivist approach, which emphasizes the construction of knowledge through experience and situational context, is an essential foundation in the studies reviewed.

Other theories and frameworks appeared in 1-2 articles, such as self-determination theory, ARCS model, human-centered design approach, computational thinking, pedagogical content knowledge, four-dimensional framework, social cognitive theory, science capital theory, cognitive theory of multimedia learning, and outcome-based education. This distribution reflects the plurality of theoretical approaches in the reviewed research, with constructivist learning theories and experience-centered learning approaches dominating, indicating a trend toward integrating technology and gamification in educational contexts.

Platforms/Applications and Mechanical Games Used in STEM Learning in Elementary Schools

Research on STEM learning using games in elementary schools shows that various platforms and applications have been utilized to facilitate student engagement and understanding. These platforms include commercial and educational digital games, AR-based applications, programming environments for developing computational thinking skills, robotics devices, and traditional and physical learning media such as board games and escape rooms (**Table 5**). This diversity reflects the flexibility of approaches when implementing game-assisted learning to support achieving STEM learning goals in elementary education.

It is important to clarify that while a total of 27 articles were included in this review, the analysis of platforms was conducted at the level of unique applications or

Table 5. Distribution of the platforms and applications used in STEM learning in the elementary school literature

Category	Platform/application	Platform/application name(s)	Game mechanics used	Reference(s)
Digital	Custom Digital Math Game	Custom Mathematics Game ["Zagonetke mudrog lisca" (Riddles of the Wise Fox)]	Time limits, progressive difficulty, immediate feedback	Juric et al. (2021)
	Embedded Digital Games in Curriculum	Sandbox, Dream 2B	Avatars/customization, unlockable content, leveling up, sandbox play, tool choice, progressive challenges	Hunt et al. (2022, 2023a, 2023b)

Table 5 (Continued). Distribution of the platforms and applications used in STEM learning in the elementary school literature

Category	Platform/application	Platform/application name(s)	Game mechanics used	Reference(s)
	Social Network/ Collab Game	Custom Math Mobile Game with Microblogging	Social collaboration, leaderboards, microblog posts	Juric et al. (2018)
	Commercial Educational Computer Game	Zoombinis	Puzzle solving, progressive challenge, failure recovery	Rowe et al. (2021)
	Immersive 3D Digital Adventure Game	Final Frontier (custom PC game: NEWTON platform)	Exploration, story/narrative, missions, rewards	Mawas et al. (2020)
	Scenario-Based Video Game	Project NEO	Scenarios, branching choices, quests	Van Eck et al. (2015)
	Tablet Apps	30 STEM applications on iPad	Points, timed activities, immediate feedback	Nang and Harfield (2018)
	Humanoid Robot Platform	NAO Robot	Physical challenges, repetition, performance feedback	Podpečan (2023)
	Digital Escape Room	BrEscapeRm	Timed puzzles, cooperative play, clues, unlocks	Ouariachi and Elving (2024)
	Commercial Sandbox Video Game	Minecraft Education Edition	Construction, exploration, level objectives	Slattery et al. (2024)
	AR Math Application	Geo+	Manipulation, visualization, immediate feedback	Rossano et al. (2020)
	AR-Based Mobile Science App	Microorganisms (custom app)	Augmented exploration, quests, collectibles	Ramli et al. (2021)
	Custom Digital Geometry Game	Custom Unity-based Geometry Game	Building, progression, star ratings, time constraints	Puig et al. (2022)
	Programming/Game Design Environment	AgentSheets, AgentCubes	project creation, debugging, achievement badges	Repenning et al. (2015)
	Roleplay Game/ Simulation Game	Logistics to the Rescue; researcher-made simulation game	Resource management, time constraints, scenario-based planning, collaboration, missions/levels	Marks et al. (2021), Mullin and Milburn (2021)
	Digital Game-Based Learning Platforms	Unnamed	N/A	Vate-U-Lan (2015), Burušić et al. (2021), Ball et al. (2020a, 2020b)
Non-digital	Physical Board Game (Student-Created)	Custom Honeybees Board Game (student-designed)	Board movement, question cards, competition	Mildenhall et al. (2021)
	Traditional Games	Traditional/local games	Movement, teamwork, roleplay, timed tasks	Orak et al. (2020)
	Physical Board Game/Design	Teacher-made Science Board Games (custom, varied)	Turn taking, question/challenge cards, competition	Botes (2024)
	Physical Puzzle game	Color Code Puzzle game	Competition, badges, team play	Bofferding et al. (2022)

platforms. Several articles investigated the same game or platform; therefore, the number of reviewed articles does not correspond directly to the number of distinct platforms identified. Based on this platform-level analysis (total platform = 20), digital platforms dominate with 16 unique applications (80.00%), while non-digital platforms account for 4 applications (20.00%), as summarized in **Table 5**. The remaining articles represent repeated examinations of previously identified platforms rather than additional unique applications.

The dominance of digital platforms reflects the technologization trend in research using games in learning and shows the researchers' preference for digital technology-based solutions. Digital platforms cover a broad spectrum from custom math games to AR-based applications. Digital GBL platforms and embedded digital games in the curriculum are popular choices, as seen in the implementation of dream 2B (Hunt et al., 2022, 2023a, 2023b), which uses a sandbox and puzzle-like play approach.

AR-based applications demonstrate innovation in learning, including through Geo+ (Rossano et al., 2020) and the microorganisms custom app (Ramli et al., 2021), both of which implement AR technology for interactive learning. Commercial game platforms adapted for education are also significant, such as Minecraft education edition and Zoombinis, which utilize the elements of construction and exploration. Although digital platforms dominate, non-digital approaches still play an essential role, with four types of applications. Physical board games show interesting variations, ranging from the custom honeybees board game that

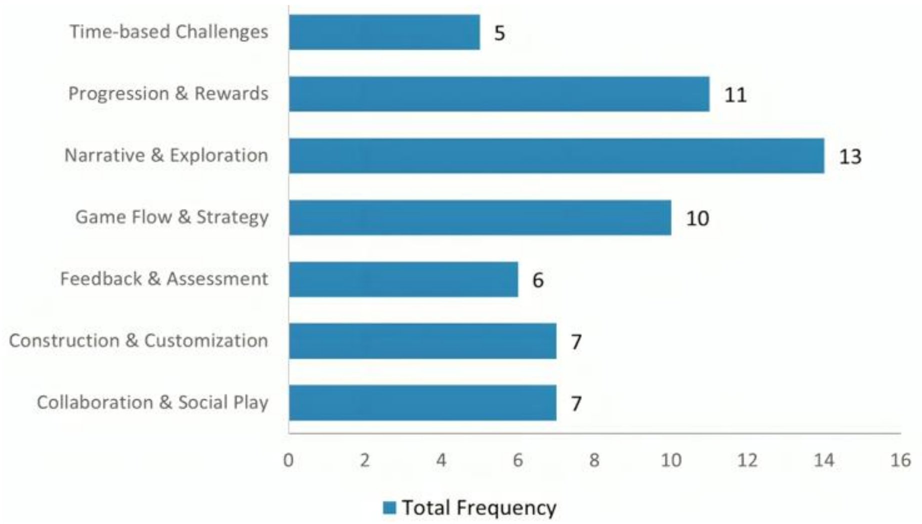

Figure 2. Frequency distribution of the game mechanics categories identified in digital and non-digital STEM learning games at the elementary school level (Source: Authors' own elaboration)

Table 6. Categories and specific game mechanics

Category	Specific game mechanics
Collaboration & social play	Collaboration, cooperative play, leaderboards, microblog posts, social collaboration, team play, teamwork
Construction & customization	Avatars/customization, building, construction, debugging, project creation, tool choice, sandbox play
Feedback & assessment	Failure recovery, immediate feedback, performance feedback, star ratings, repetition, visualization
Game flow & strategy	Badges, board movement, competition, movement, question cards, question/challenge cards, resource management, scenario-based planning, turn taking, puzzle solving
Narrative & exploration	Augmented exploration, branching choices, collectibles, exploration, quests, scenarios, story/narrative, manipulation, physical challenges, progressive challenge, progressive difficulty, clues, roleplay
Progression & rewards	Achievement badges, leveling up, missions, missions/levels, points, progression, progressive challenges, rewards, unlockable content, level objectives, unlocks
Time-based challenges	Time constraints, time limits, timed activities, timed puzzles, timed tasks,

was explicitly designed by students, to teacher-made science board games. Traditional games are also used in STEM learning research in elementary schools.

The distribution of the game mechanics used in STEM learning in elementary schools is presented in **Figure 2** and **Table 6**. In both digital and non-digital games analyzed in related studies, game mechanics were identified and categorized into seven main categories, with frequencies ranging from 5 to 13 occurrences.

Categories tied for the highest were narrative and exploration (n = 13, 22.03.%), which included fundamental mechanics like branching choices, quests, and story-driven elements. This result was followed by the progression and rewards category (n = 11, 18.64%) that featured mechanics such as achievement badges, leveling up, missions, missions/levels, points. At the same time, game flow and strategy focused on achievement badges, board movement, competition, movement, question cards, question/challenge cards, resource management, scenario-based planning, turn taking, and puzzle solving (n = 10 each, 16.95%). Both collaboration and social play, and construction and customization, showed equal frequencies and recorded 7 occurrences (11.86%), representing building mechanics and performance in collaboration systems, respectively. Notably, the feedback and assessment category recorded 6 occurrences (10.17%), highlighting the role of immediate performance reflection in the learning process. The lowest frequency was observed in time-based challenges (n = 5, 8.47%), which included time constraints, timed activities, and temporal puzzle elements. This heterogeneity in game mechanics indicates the evolving nature of game design, where innovative mechanics are being developed to enhance player engagement beyond conventional frameworks. The various game mechanics are designed to create an adaptive, challenging, and enjoyable learning environment. The variety of mechanics used suggests that their use in STEM learning serves not only as a motivational tool but also as an effective pedagogical strategy in supporting elementary school students' cognitive, affective, and social development.

Table 7. Distribution of the potential effects of STEM learning using games in the elementary school literature

Potential effects	Description	References	F
STEM conceptual understanding	Improved mastery of STEM concepts through interactive, gamified environments	Ball et al. (2020a), Botes (2024), Hunt et al. (2022, 2023b), Marks et al. (2021), Mawas et al. (2020), Mildenhall et al. (2021), Puig et al. (2022), Ramli et al. (2021), Rossano et al. (2020), Van Eck et al. (2015)	11
Student engagement & motivation	Increased learner interest and engagement via game elements like challenges, interactivity, and rewards	Hunt et al. (2022), Juric et al. (2018), Marks et al. (2021), Mawas et al. (2020), Mildenhall et al. (2021), Mullin and Milburn (2021), Orak et al. (2020), Podpečan (2023), Puig et al. (2022), Ramli et al. (2021), Rossano et al. (2020), Van Eck et al. (2015), Yllana-Prieto et al. (2023)	13
Collaboration and social skills	Gamified learning often involves teamwork and fosters communication and collaboration	Botes (2024), Hunt et al. (2023b), Juric et al. (2018), Mildenhall et al. (2021), Orak et al. (2020), Yllana-Prieto et al. (2023)	7
Critical thinking and problem-solving	Students develop reasoning and analytical thinking by solving in-game challenges	Bofferding et al. (2022), Juric et al. (2021), Mawas et al. (2020), Mullin and Milburn (2021), Vate-U-Lan (2015)	5
STEM identity and motivation	Enhancement of STEM identity and motivation, particularly in underrepresented groups	Ball et al. (2020a, 2020b), Burušić et al. (2021), Cohen et al. (2021), Repenning et al. (2015), Slattery et al. (2024)	6
Digital literacy & technology self-efficacy	Games improve familiarity and confidence in using digital tools and technologies	Ball et al. (2020a), Bofferding et al. (2022), Cohen et al. (2021), Juric et al. (2021), Kefalis et al. (2025), Marks et al. (2021), Page et al. (2021)	7
Creativity and design thinking	Opportunities for game creation and the exploration of solutions that promote student creativity	Botes (2024), Mildenhall et al. (2021), Repenning et al. (2015)	3
Teacher development and pedagogical practice	Improved instructional strategies and confidence among teachers using gamified approaches	Botes (2024), Hunt, Taub, Marino, et al. (2023), Van Eck et al. (2015), Vate-U-Lan (2015)	4
Assessment and feedback	Games provide embedded assessments and real-time feedback for students and teachers	Hunt et al. (2023b), Mawas et al. (2020), Ramli et al. (2021), Rowe et al. (2021)	4
Equity and inclusion	Supports learning for diverse student populations and helps bridge digital and STEM divides	Ballet al. (2020a, 2020b), Cohen et al. (2021), Juric et al. (2021), Rowe et al. (2021), Slattery et al. (2024)	6
Spatial thinking & visualization	Improved ability in geometry, spatial orientation, and visual reasoning	Bofferding et al. (2022), Puig et al. (2022), Rossano et al. (2020), Slattery et al. (2024)	4
Affective and emotional outcomes	Enhanced enjoyment, emotional connection, and positive attitudes towards learning	Orak et al. (2020), Podpečan, 2023), Ramli et al. (2021), Rossano et al. (2020), Yllana-Prieto et al. (2023)	5

Note. F: Frequency

Potential Effects of STEM Learning Using Games in Elementary Schools

Implementing gamified STEM learning in elementary schools has shown there to be a variety of potential positive impacts on students and the learning environment, as presented in **Table 7**. These effects generally include improved academic and social-emotional outcomes, the forming of STEM identity, increased student engagement, and transforming the teachers' teaching practices. The most dominant effect was Increased Student Engagement and Motivation, which appeared 13 times. This result shows that game elements such as challenges, interactivity, and reward systems can increase the students' interest and active participation in STEM learning.

The next effect that is also frequently found is STEM conceptual understanding, with a frequency of 11. This finding shows that game-based STEM learning environments significantly support the mastery of STEM concepts through interactive and fun learning experiences. Digital literacy and technology efficacy appeared 7 times, indicating that games in STEM learning can increase students' confidence and skills in digital technology. The other four categories have moderate frequencies, namely collaboration and social skills (7 times), STEM identity and motivation (6 times), equity and inclusion (6 times), and critical thinking and problem-solving (5 times). Game interactions often encourage collaboration, communication, and healthy competition, contributing to the students' holistic development. In group games, students learn to resolve conflicts, listen to others' opinions, and achieve common goals, which are essential social skills in both academic and professional life.

Other categories such as affective and emotional outcomes, teacher development and pedagogical practices, assessment and feedback, spatial thinking and visualization, and creativity and design thinking have

Table 8. Key factors influencing the implementation of games for STEM learning in the elementary school literature

Primary factor	Specific factors	References	TF
Pedagogical alignment	Curriculum integration, subject relevance, instructional design	Bofferding et al. (2022), Hunt et al. (2023b), Juric et al. (2021), Marks et al. (2021), Mawas et al. (2020), Mildenhall et al. (2021), Nang and Harfield (2018), Orak et al. (2020), Ramli et al. (2021), Van Eck et al. (2015)	10
Learner engagement	Interactive gameplay, motivation, emotional engagement, student agency, playful design, student satisfaction	Hunt et al. (2022), Mawas et al. (2020), Mildenhall et al. (2021), Podpečan (2023), Puig et al. (2022), Ramli et al. (2021), Rossano et al. (2020), Slattery et al. (2024), Vate-U-Lan (2015), Yllana-Prieto et al. (2023)	10
Technology design	Usability, accessibility, AR integration, platform features, privacy protection	Juric et al. (2018), Mawas et al. (2020), Nang and Harfield (2018), Ramli et al. (2021), Rossano et al. (2020)	5
Teacher role & support	Teacher preparedness, professional development, beliefs and confidence, implementation fidelity, teacher support and endorsement	Botes (2024), Hunt et al. (2023b), Marks et al. (2021), Mildenhall et al. (2021), Puig et al. (2022), Repenning et al. (2015), Van Eck et al. (2015)	7
Social and collaborative learning	Cooperative tasks, collaborative opportunities, social interaction features	Juric et al. (2018), Mildenhall et al. (2021), Orak et al. (2020), Yllana-Prieto et al. (2023)	4
Contextual and cultural relevance	Real-world problems, sociocultural dynamics, language considerations, student background	Burušić et al. (2021), Cohen et al. (2021), Mildenhall et al. (2021), Mullin & Milburn, 2021), Vate-U-Lan (2015)	5
Assessment and feedback	Built-in assessments, immediate feedback, educational data mining	Mawas et al. (2020), Ramli et al. (2021), Rowe et al. (2021)	3
Equity and inclusion	Gender and SES accommodation, learner variability, accessibility	Ball et al. (2020a, 2020b), Burušić et al. (2021), Hunt et al. (2022, 2023b), Juric et al. (2021)	6
STEM identity & motivation	Early STEM experiences, identity capital, STEM attitudes	Ball et al. (2020a, 2020b), Burušić et al. (2021), Cohen et al. (2021)	4
Infrastructure and resources	Availability of tools, xlassroom support, resource adequacy	Nang and Harfield (2018), Slattery et al. (2024), Van Eck et al. (2015), Vate-U-Lan (2015)	4
Game structure & design	Game mechanics, duration of exposure, adaptive personalization	Bofferding et al. (2022), Juric et al. (2021), Puig et al. (2022), Rowe et al. (2021), Van Eck et al. (2015), Yllana-Prieto et al. (2023)	6
Policy and implementation	Stakeholder buy-in, supportive policies, scalability	Repenning et al. (2015), Vate-U-Lan (2015)	2

Note. TF: Total frequency

lower frequencies (3-5 times). This shows that not only students, but also teachers, gain significant benefits from implementing gamification. Their involvement in designing and implementing educational games encourages pedagogical development, especially among prospective teachers. They learn to deliver content in a creative, inclusive, and appropriate way to meet the needs of learners. Overall, evidence from various literatures shows that implementing games in STEM learning in elementary schools has transformative potential. The use of games not only improves academic outcomes and student motivation but also shapes the identities, attitudes, and skills that are relevant to the needs of the 21st century. Therefore, the strategic and sustainable integration of games into the STEM curriculum can be a promising approach to building inclusive, adaptive, and meaningful learning experiences.

Characteristic Factors Affecting the Implementation of Gamified STEM Learning in Elementary Schools

In this analysis, the main factor that can support the success of STEM learning with the help of games in elementary schools is pedagogical alignment with 10 references (**Table 8**). The most frequently cited factor shows that alignment with the curriculum and educational standards is a top priority in educational game research. “Curriculum integration, subject relevance, and instructional design” in this factor aims to ensure that the technology used is truly aligned with the learning objectives that have been set. The alignment of the curriculum with game content or technology is an essential basis for ensuring there is no disconnection between the media and teaching materials. Appropriate instructional design is also a vital catalyst for optimizing the implementation of this innovation in the classroom.

In addition to pedagogical appropriateness, learner engagement is an equally prominent factor, with 10 references. This validates the premise that student engagement is a key element in the effectiveness of educational games. This category includes elements such as interactive gameplay, motivation, emotional engagement, student agency, playful design, and student satisfaction, indicating that interactivity and playful design in games can significantly increase student motivation and satisfaction. The studies reviewed show that emotional engagement through games strengthens the students' understanding of the material (Hunt et al., 2022; Puig et al., 2022; Rossano et al., 2020). Thus, adaptive and entertaining game design elements are highly recommended to create a deep and meaningful learning experience.

The teacher role and support factor (7 references) is no less critical, including teacher preparedness, professional development, beliefs and confidence, implementation fidelity, and teacher support and endorsement. Teachers act as facilitators and are the main drivers implementing this technology. Therefore, the teachers' beliefs in the benefits of technology, professional training, and their readiness to implement educational games consistently determines this learning strategy's success. In this context, institutional support in the form of supportive policies and adequate resources are also complementary elements that strengthen the effectiveness of GBL technology in schools.

DISCUSSION

The synthesis of the 27 articles shows that a mixed methods approach plays a significant role in capturing the dynamics of game-based STEM learning, especially at the elementary school level. The combination of quantitative and qualitative data enriches the perspectives and allows for an in-depth exploration of how students engage cognitively and affectively with games. While the experimental studies reveal improvements in spatial skills or creativity, qualitative approaches complement those findings by explaining why and how engagement occurs. This result reinforces the idea that games operate as transformative learning environments that are complex, interactive, and social, where understanding is constructed and lived. The meaning of learning in games is shaped not just by the content or mechanics, but by how learners interact with each other, the world, and themselves in the process of play (Ball et al., 2020a; Hunt et al., 2022; Orak et al., 2020; Puig et al., 2022; Repenning et al., 2015) Therefore, the choice of methodology is not only a technical decision but also a reflection of a paradigm that defines learning as a multidimensional process. The diversity of research methodologies reflects the complexity of the topics studied and shows that no one methodological approach is dominant. This result indicates that research in this domain requires various methodological techniques to understand the phenomenon comprehensively from multiple perspectives.

The use of various theories in the analyzed studies indicates a serious effort to understand and design GBL in a more comprehensive and learner-oriented way. Neo-Piagetian theory, social constructivism, and experiential learning/inquiry-based learning emerged as the dominant theories, indicating the importance of an approach that positions students as active builders of their knowledge through authentic, explorative, and reflective experiences. Neo-Piagetian theory allows for a more granular mapping of cognitive development, especially in developing logical and spatial reasoning through games (Bofferding et al., 2022). Social constructivism emphasizes the role of social interaction and language in constructing meaning.

In contrast, experiential and inquiry-based learning emphasizes the students' active involvement in learning through experiments, investigations, and projects. Experiential learning immerses students in activities where they do and reflect, making them more motivated and engaged. For instance, gamification strategies, like escape rooms and breakout games, have been employed to teach STEM content with notable success. Such approaches foster cooperation, critical thinking, and a sense of accomplishment, with students reporting increased motivation, enjoyment, and focus during these activities. However, attention to the affective domain is crucial, especially for elementary school students whose emotions can significantly impact learning. Promoting positive experiences with STEM early on is essential to shaping positive attitudes and long-term engagement (Yllana-Prieto et al., 2023).

GBL theory and gamification as an educational model appear in three articles. The reviewed studies illustrate and reinforce the contemporary educational shift toward treating GBL and gamification as sophisticated, structure-rich pedagogical models. The findings from these papers align closely with a rapidly advancing research tradition that contends that games are not merely a supplement to instruction, but foundational architectures for learning in the 21st century classroom (Mawas et al., 2020; Puig et al., 2022; Yllana-Prieto et al., 2023). In addition, UDL shows a moderate level of use, demonstrating a commitment to the principles of accessibility and flexibility in designing games that can reach various student learning needs and profiles.

Meanwhile, classical theories such as Piaget's constructivism and situated learning are still quite often used as theoretical bases. This confirms that despite the emergence of new approaches, old theoretical foundations remain relevant in explaining how children construct knowledge actively and contextually. The overall use of this theory reinforces the meaning that game integration in education is not only about effectiveness, but also about building meaningful, equitable, and transformative learning experiences. Theory becomes a lens to see games not just as media, but as pedagogical spaces that allow for the reconstruction of meaning and student learning agency.

The dominance of digital platforms such as Minecraft and AR applications in the literature reflects global trends in learning innovation but also raises critical reflections on the gaps in access and local contexts. This is supported by Alahmari et al. (2023), who revealed that most research has historically been concentrated on higher education, largely because teaching-learning lessons there are already technology-based and, crucially, because gamification applications are often too expensive for many schools to afford. This high cost associated with advanced technology explains why there is a lack of exploration of non-digital games, such as board games or traditional games that are easily accessible. This is an essential signal for researchers and education practitioners in developing countries, including Indonesia, to explore and establish GBL forms based on local cultural values that are community-based, and low-cost. Thus, the development of STEM learning is not just a technological agenda, but also a movement towards educational justice and social sustainability. Furthermore, the significant variation in the use of different game mechanic categories reflects the complexity and diversity of approaches required to implement gamification effectively across different economic and educational settings.

Narrative and exploration and progression and rewards have the first and second highest frequencies, respectively, indicating a balance between the individual motivational aspect through the reward system and the exploration aspect of in-depth learning. Rewards provide extrinsic motivation and clear goals, while progression offers a sense of achievement and mastery as learners advance through the tasks (Puig et al., 2022). Narrative and exploration give learning tasks meaning, context, and personal relevance (Hunt et al., 2022). This aligns with self-determination theory, which emphasizes the importance of autonomy, competence, and relatedness in learning (Hunt et al., 2023b).

The game flow and strategy mechanic category includes badges, board movement, competition, resource management, and scenario-based planning. The dominance of this category indicates that researchers and practitioners recognize the importance of structured and strategic game flows—like those found in Blooket—to maintain student engagement (Algburi et al., 2026). This mechanism highlights that optimal learning arises when challenge and ability are balanced, being neither too easy nor too hard. Such a principle is essential in designing STEM tasks that enable all students to experience success and growth. As noted by Repenning et al. (2015). Educators can foster this flow by tuning the difficulty in response to the skill of their students, thereby unlocking deep and enduring learning through platforms that balance strategic challenges with immediate motivational rewards.

Collaboration and social play show that there is moderate attention paid to the social aspects of learning, which supports the theories of social constructivism and collaborative learning. Mechanisms such as cooperative play, leaderboards, and team play reflect the understanding that STEM learning requires not only the individual but also meaningful social interactions (Mildenhall et al., 2021). The slightly balanced distribution between construction and customization and feedback and assessment shows recognition of the importance of active student involvement in the learning process and the need for continuous feedback. When students construct or customize within a learning environment, they are not passive recipients, but the creators and engineers of meaning (Puig et al., 2022; Rossano et al., 2020). Regular formative feedback and assessments from systems, peers, or teachers enable students to correct misconceptions, experiment, iterate, and achieve the learning goals more efficiently and confidently (Hunt et al., 2022).

Time-based challenges may indicate that time pressure is not always necessary or may even be counterproductive in STEM learning at the elementary school level. This is consistent with research showing that when a suitable amount of time constraint is applied to learners, it stimulates positive emotional responses and enhances their creativity (Tsai et al., 2018). Future research should explore different game mechanics' relative effectiveness and synergistic interactions in improving STEM learning outcomes.

This heterogeneity in game mechanics indicates the evolving nature of game design, where innovative mechanics are being developed to enhance player engagement beyond conventional frameworks. The various game mechanics are designed to create an adaptive, challenging, and enjoyable learning environment. The mechanics suggests that their use in STEM learning serves not only as a motivational tool but also as an effective pedagogical strategy in supporting elementary school students' cognitive, affective, and social development.

Various interconnected factors influence the implementation of games in STEM learning in elementary schools. The pedagogical alignment factor is essential for successful implementation, including curriculum integration, subject matter relevance, and appropriate instructional design (Botes, 2024). In addition, learner engagement emerges as a dominant, central factor in elementary STEM learning through games. It is most powerfully strengthened by interactive mechanisms (active participation), fun and immersive designs, and robust support for student agency and satisfaction. These factors work synergistically to increase motivation, deepen learning, and cultivate a lasting interest in STEM, as demonstrated across multiple research studies and real classroom implementation (Hunt et al., 2022; Mawas et al., 2020). Thus, adaptive and entertaining game design elements are highly recommended to create a deep and meaningful learning experience.

Technology support is also an important determinant, where ease of use (usability), accessibility, and the integration of features such as AR and privacy protection are crucial in supporting games' sustainability in a learning environment. For example, the Geo+ AR application (Rossano et al., 2020) was developed with a human-centered approach, focusing on ease of use. The user study conducted with elementary school students demonstrated that pupils found the application easy to use; they could engage with activities independently without needing additional support. High usability increases satisfaction and engagement, improving learning outcomes (Rossano et al., 2020). Additionally, the accessibility features that adapt to individual needs are important. For instance, content personalization and adaptation help accommodate various learning styles and physical abilities (Mawas et al., 2020).

Furthermore, the role of teachers occupies a central position in the success of game implementation, as reflected in the teacher role and support category. This factor includes teacher readiness, professional training, belief in the effectiveness of educational games, and the suitability of implementation in the field. Effective professional development must integrate game tools, pedagogy, and classroom strategies. Teachers' positive beliefs increase the likelihood of game adoption. Still, actual implementation is often mediated by practical considerations, such as time constraints, perceived relevance to curricular objectives, and teachers' comfort with technology (Hunt et al., 2023b). Many face challenges related to familiarization time, lack of resources, or insufficient instructional guidance. Professional development initiatives, such as workshops and collaborative communities of practice, have been shown to help teachers gain confidence and expertise in using educational games, thereby improving integration with their instructional goals and boosting the sustainability of program implementation (Repenning et al., 2015).

On the other hand, social factors such as social and collaborative learning and contextual and cultural relevance have also been shown to support learning effectiveness. Adequate infrastructure, learning resources, flexible and conducive policies, and stakeholder support also support implementation success. Teachers emphasize the importance of reliable access to devices and ongoing technical support to address issues promptly, ensuring a smooth learning experience for all students (Slattery et al., 2024). This indicates that the success of the game in STEM learning is determined by the quality of the game and the readiness of the education ecosystem as a whole. Thus, gamification implementation in elementary schools in STEM learning needs to be designed holistically by considering pedagogical, technological, social, and policy aspects.

The next finding is related to the potential effects of using games. The most prominent potential effect of game use in STEM learning is the dominance of conceptual understanding, which shows that the use of games in STEM learning consistently and significantly impacts the mastery of fundamental concepts. The high frequency of conceptual understanding can be explained through several psychological and pedagogical mechanisms. First, games provide a safe environment to experiment and make mistakes without adverse consequences, so students are more willing to try different approaches to understanding concepts (Juric et al., 2021). Second, gamification elements such as points, badges, and leaderboards provide immediate feedback that helps students understand their level of understanding in real-time (Puig et al., 2022). Third, the engaging narrative and context in the game helps students relate more abstract concepts to concrete, easy-to-understand situations (Hunt et al., 2022).

The findings related to STEM Identity and Motivation suggest that gamification plays an important role in shaping the students' perceptions of STEM and fostering long-term interest. This is especially important given the challenges in attracting students, especially those from underrepresented groups, to pursue careers in STEM fields. Games can serve as a gateway that makes STEM seem interesting, achievable, and relevant to everyday life. The formation of STEM identity through games occurs through identification and internalization. Students who complete challenges in STEM games begin to see themselves as capable individuals. Repeated successful experiences build self-confidence and a sense of belonging in STEM fields. Additionally, diverse representation in the game characters and narratives can help students from different backgrounds see that STEM is a field that is open and relevant to them (Cohen et al., 2021). In addition, gamification also contributes to developing crucial 21st century skills, including digital literacy, collaboration, and problem-solving.

The results show that not only students, but also teachers, gain significant benefits from implementing gamification. Involvement in designing and implementing educational games encourages pedagogical development, especially among prospective teachers. They learn to deliver content in a creative, inclusive, and appropriate way to meet the needs of learners. Overall, evidence from the literature shows that implementing games in STEM learning in elementary schools has transformative potential. The use of games not only improves academic outcomes and student motivation but also shapes identities, attitudes, and skills that are relevant to the needs of the 21st century. Therefore, the strategic and sustainable integration of games into the STEM curriculum can be a promising approach to building inclusive, adaptive, and meaningful learning experiences.

The research findings from our five RQs demonstrate that the diversity of methodological approaches in the study of educational games for STEM learning in elementary schools is closely intertwined with the underlying theoretical framework. The predominance of mixed methods, experimental, and design-based designs reflects the need to capture learning effectiveness quantitatively while simultaneously understanding student learning processes qualitatively. This trend aligns with the adoption of theoretical models such as neo-Piagetian, social constructivism, and experiential learning, which emphasize active learning, knowledge construction through interaction, and direct experience. Thus, the choice of intervention-oriented methodologies and design development can be understood as a logical consequence of the constructivist pedagogical foundations that dominate these studies.

This integration of methodology and theory is reflected in game design practices, particularly through the predominance of digital platforms and narrative and exploration-based mechanisms. These mechanisms allow students to gradually build their conceptual understanding through experience, reflection, and decision-making, while minimizing excessive cognitive pressure on elementary school students, as demonstrated by the low use of time-based challenges. This alignment between methodology, theory, and game design directly contributes to the most consistently reported educational impact of increased student engagement and motivation. However, this impact can only be optimized if supported by strong implementation factors, such as curriculum integration, material relevance, and aligned instructional design. Therefore, these findings confirm that the success of educational games for STEM learning in elementary schools is determined by the synergy between the research methodology, theoretical foundations, game design, and the educational implementation context.

Previous SLRs have provided important foundations for understanding the use of educational games and serious games in STEM learning (Gao et al., 2020; Kustiyarto & Marhaeni, 2025; Tene et al., 2025; Vásquez-Carbonell, 2022), but they have remained limited in their focus on elementary education, integration across STEM domains, and comprehensive analysis linking theory, game design, educational impact, and implementation factors. This study expands on these findings by focusing exclusively on the elementary school context, covering all STEM domains, and utilizing the curated Scopus database. The results indicate that the dominant methodological approaches are mixed methods, experimental, and design-based, which aligns with the adoption of neo-Piagetian, social constructivism, and experiential learning theories. In addition to confirming the dominance of digital platforms, the study revealed that narrative-based and exploration-based game mechanics were more widely used than time-pressured challenges, reflecting their suitability related to the cognitive developmental needs of elementary school students. Furthermore, the findings indicate that increased student engagement and motivation were the most consistent educational outcomes, and that implementation success was strongly influenced by pedagogical alignment, curriculum integration, and instructional design. Thus, this SLR not only updates the mapping of the previous research but also offers a holistic synthesis that systematically connects methodology, theory, game design, educational impact, and implementation context in STEM learning in elementary schools.

Implications and Limitations

The practical implications of the results for learning practice can be detailed. Based on the findings of this study, it is clear that the effectiveness of educational games for STEM learning in elementary schools depends heavily on the pedagogical alignment between the game and the learning objectives. Educational games need to be positioned as a core learning strategy systematically integrated into STEM learning plans, rather than as supplementary activities. This approach aligns with the principles of constructivist and inquiry-based learning, where students build their conceptual understanding through exploration, reflection, and social interaction. The dominance of mixed methodologies in the research also emphasizes the importance of reflective practice in the classroom, which encourages teachers to not only evaluate cognitive achievement but also to monitor student engagement, motivation, and thinking processes. Thus, formative assessments based on observation, discussion, and play artifacts become an important component of game-based STEM learning practices in elementary schools.

From a design and policy perspective, these findings emphasize that effective STEM educational games must be grounded in strong learning theories, particularly social constructivism and experiential learning. They should be designed to facilitate decision-making, contextual problem-solving, and reflection through mechanisms such as narrative and exploration. The dominance of digital platforms opens up both opportunities and challenges for developing flexible, adaptive, and inclusive games, while the lack of non-digital games highlights a gap in research and practice, particularly in school contexts with a limited infrastructure. At the policy level, structural support is needed through the explicit integration of GBL into the STEM curriculum, strengthening teacher competencies in game-based instructional design, and investing in the development and validation of educational games aligned with the national curriculum. With an integrated approach, educational games have the potential to become catalysts for meaningful, contextual, and sustainable STEM learning in elementary schools.

This study has several limitations that should be acknowledged. First, the data extraction and coding process was conducted solely through a process in which one researcher served as lead coder and the others acted as reviewers to align interpretations through iterative discussions. This approach was chosen because the analytical categories examined were conceptual and complex, such as theoretical frameworks and game mechanics. Because the coding was not conducted in parallel and was done independently from the outset by more than one rater, statistical measures of inter-rater reliability, such as Cohen's kappa, could not be calculated. Consequently, the level of coding consistency could not be quantitatively verified, potentially impacting the replication of the results, particularly for categories with a high degree of interpretability.

Second, although these limitations were mitigated through multiple review sessions, face-to-face discussions, the clarification of the category definitions, and iterative revisions of the coding framework until consensus was reached, this approach still cannot fully replace objective quantitative evidence of reliability. Third, limiting the data source to the Scopus database could potentially exclude relevant studies indexed in other databases or grey literature, making the findings of this study more representative of the research trends published in reputable international journals. Fourth, the exclusive focus on STEM learning in elementary schools limits the generalizability of the findings to other educational levels or non-STEM contexts. Therefore, the findings of this study should be understood as general trends, opening up opportunities for future research to apply independent parallel coding with statistical reliability measures and to expand the scope of the contexts and data sources.

CONCLUSION

In summary, this systematic review aims to explore the impact of games on STEM education in elementary schools for both students and teachers, and to explore the factors that influence it through the literature. By carefully analyzing 27 studies published between 2015 and June 2025, we have provided a comprehensive synthesis of the current research on games in STEM education in elementary schools. The findings suggest a diverse methodological orientation, with mixed-methods being the most frequently employed approach (22.22%), highlighting the value placed on capturing both quantitative and qualitative learning phenomena. Experimental methodologies (22.22%) strongly emphasize evaluating the interventions and developing practical educational tools. A range of theoretical frameworks, including neo-Piagetian theory, social constructivism, and experiential learning theory, frequently underpin these studies, suggesting a shared foundation in constructivist and inquiry-based pedagogies.

Digital platforms overwhelmingly dominate the implementation of game-based STEM education, with 80.00% of studies utilizing digital applications. Despite this, non-digital games, including board games, remain underrepresented. Various game mechanics were identified from a design perspective, with narrative and exploration being the most prevalent, and time-based challenges being the least. Key enabling factors such as pedagogical alignment were consistently cited as essential for effective integration, while the most prominent reported outcomes include increased student engagement and motivation.

Finally, while digital games have dominated the research space, the potential of physical, tabletop, and student-designed board games remains underexplored. These formats may offer unique affordances for promoting collaborative problem-solving, tangible learning experiences, and community-based STEM engagement. Future research should pursue robust, theory-driven studies on board games to understand their distinct contributions and develop inclusive, engaging, and context-sensitive GBL strategies for elementary STEM education. Therefore, we recommend that:

1. More robust empirical designs and greater attention paid to non-digital educational games: Digital learning environments and gamification, AR applications, video games, and simulation games in STEM have received increasing research attention, including studies measuring cognitive and affective outcomes, classroom dynamics (Botes, 2024; Mullin & Milburn, 2021). The role of traditional and physical games (including puzzle and logic games) has also received considerable attention. Still, board games as a distinct focus of research are emerging, especially those that are not digital adaptations but in physical, tabletop, or student-designed formats (Botes, 2024; Mullin & Milburn, 2021). There is a clear need for more rigorous and systematic research on the role of board games in elementary STEM education. Although the existing literature highlights their potential, particularly for student engagement, collaborative learning, and community outreach, board games remain under-researched compared to digital and simulation-based games. Future research should use robust empirical methods and inclusive design principles to address their unique strengths, contexts for success, and potential to broaden and deepen STEM learning in elementary schools.
2. Longitudinal studies examining long-term learning outcomes such as retention, sustained engagement, and STEM identity development: Research on game-assisted STEM learning in elementary schools has demonstrated various benefits. Some future research avenues have not

been widely explored and are critical to fully understanding the impact and optimizing implementation. Many studies rely on small sample sizes, case studies, convenience samples, or data from a narrow demographic or single location, which limits generalizability across settings, ages, and cultures (Cohen et al., 2021; Marks et al., 2021; Ramli et al., 2021; Van Eck et al., 2015). This suggests the potential for future studies recruiting larger, more diverse, and representative groups. Additionally, studies often capture only short-term effects (engagement, perception, immediate learning outcomes) without data on long-term retention, STEM identity development, or sustained behavior or career impact (Marks et al., 2021; Repenning et al., 2015; Slattery et al., 2024). This is potential in the future for implementing research tracking the effects over months or years to assess retention, continued engagement, the development of STEM identity, and real-world outcomes.

3. Research focusing on teacher professional development and implementation fidelity: In other studies, differences in teacher background, beliefs, and fidelity related to implementation introduce heterogeneity that can confound outcomes or limit scalability (Hunt et al., 2023a, 2023b; Marks et al., 2021). Future research in this area is recommended to examine and support consistent teacher professional development, to provide a clear framework for curriculum fidelity, and to study how different teacher beliefs and backgrounds influence student outcomes.
4. Studies that isolate the effects of specific game mechanics and design features: Studies sometimes find positive outcomes (e.g., more engagement or motivation) but lack clarity on which aspects of the intervention are responsible or how particular design features drive those outcomes (Hunt et al., 2023a; Slattery et al., 2024). In the future, research could be conducted to analyze which specific elements of the playful design, gamification, or agency are the most impactful. For example, using narrative, real-world context, competition vs. collaboration, scaffolding methods, and feedback systems.

There is limited attention paid to the experiences of students with learning differences, to those from underrepresented groups, and to those in varied socioeconomic contexts, affecting the understanding of equity and accessibility (Ball et al., 2020a; Cohen et al., 2021). In the future, other researchers may explore how interventions affect subgroups based on gender, ability, socioeconomic status, or cultural context to address diversity, equity, and inclusion issues.

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AI statement: The authors stated that, during the preparation of this work, the authors utilized Grammarly solely to enhance minor linguistic clarity and grammatical accuracy of the manuscript. Following the use of this tool, the authors reviewed and edited the content to ensure its integrity; the final draft was further refined by a professional proofreader. The authors further stated that all conceptualization, research design, data collection, analysis, interpretation of findings, and academic arguments were conducted independently. No AI tools were used in data analysis, result generation, or the formulation of the study's core findings. The authors take full responsibility for the final content of the publication.

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

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