J-MS
JOURNAL MOBILE TECHNOLOGIES

Received: 26 Jan 2026 | Revised: 4 Feb 2026 | Accepted: 5 Feb 2026 | Published: 10 Feb 2026 | E-ISSN: 2986-478X, P-ISSN: 2986-1535

DOI: 10.59431/jms.v4i1.709

RESEARCH ARTICLE

Comprehensive Analysis of the Role of Mobile Application Gamification in Science Education for Motivation and Knowledge Retention

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Funding information

Deputy for Research and Development Strengthening Ministry of Research and Technology/ National Research and Innovation Agency of the Republic of Indonesia.

Abstract

Low student motivation and knowledge retention in abstract science concepts remain significant challenges in modern science education. This study aims to comprehensively analyze the role of mobile application gamification in enhancing student engagement and strengthening long-term memory. The method employed is a Systematic Literature Review (SLR) following the PRISMA 2020 protocol, involving a rigorous selection of 10 reputable international journal articles (Scopus Q1-Q4) published between 2020 and 2026. Findings indicate that competitive elements, such as leaderboards, significantly trigger intrinsic motivation, while interactive visualizations through AR and simulations effectively improve knowledge retention by simplifying complex cognitive concepts. Despite a identified research gap regarding long-term sustainability in resource-limited environments, this study concludes that a balanced integration of visual aesthetics and pedagogical depth fosters sustainable mastery of science concepts. These results provide strategic contributions for educators in designing evidence-based, inclusive, and adaptive learning media.

Keywords

Mobile Gamification; Science Education; Learning Motivation; Knowledge Retention; Systematic Literature Review.

1 | INTRODUCTION

The integration of mobile technology in the science education landscape has grown rapidly, shifting the learning paradigm from conventional methods to a more student-centered approach through Mobile Learning. In recent years, global literature has shown a significant surge in research on the application of gamification—the use of game design features in non-game contexts—as a pedagogical strategy to create immersive and interactive learning environments. Recent bibliometric analysis confirms that the trend of publications regarding gamification in science education has increased exponentially, especially in the period 2023 to 2024, reflecting strong global interest in the potential of technology in bridging the gap in student engagement in the digital age (Nurfadilah *et al.*, 2025; Saputra *et al.*, 2025). Despite the advancement of educational technology, Natural Sciences (IPA) education still faces fundamental challenges related to students' perception that these subjects, especially physics and chemistry, are abstract and difficult to understand. Difficulty in visualizing science concepts often leads to a decrease in intrinsic motivation and academic anxiety, which ultimately hinders the achievement of optimal learning outcomes (Angub *et al*., 2025). Traditional teaching methods often struggle to sustain students' interest, requiring innovative interventions that can change classroom dynamics. Adaptive gamification in mobile apps has been shown to overcome these barriers by providing a safe environment for students to experiment and learn from mistakes without fear, which significantly increases their motivation compared to traditional inquiry methods (Zourmpakis *et al*., 2023).

The application of game features such as points, badges, leaderboards, and instant feedback within mobile apps offers powerful psychological mechanisms to strengthen students' cognitive and emotional engagement. In the context of learning biology and physics, gamification not only serves as a trigger for momentary motivation but also plays a crucial role in facilitating deeper understanding of concepts through interactive simulations. Recent meta-analysis studies confirm that the use of game-based apps significantly improves student learning achievement by providing fun and competitive learning experiences, which effectively transform passive learning behavior into active participation (Diaz & Loñez, 2024; Jihadillah, 2025). However, despite these positive findings, there is a significant gap in the literature regarding the long-term impact of gamification, particularly on the aspect of knowledge retention or students' memory of science concepts. Many previous studies have tended to focus on short-term engagement and immediate exam outcomes, while analyses of "deferred concept retention" remain limited (Tanilong & Cheng, 2026). In addition, the effectiveness of gamification in improving knowledge retention relies heavily on proper instructional design; poorly structured applications risk simply becoming entertainment without substantial cognitive impact (Dewi *et al*., 2024). Therefore, further study is needed on how specific features in gamified mobile apps can be designed to ensure that increased motivation is directly correlated with long-term information retention.

This article aims to analyze the role of mobile application gamification in science education, with a specific focus on the mechanism of increasing motivation and retention of students' knowledge. Through a systematic review of recent empirical studies, this article will identify the game design features that are most effective in strengthening students' long-term memory and engagement, even in school environments with limited resources (Maryani *et al*., 2025). The expected benefits include theoretical enrichment of the science education technology literature, as well as practical implications for curriculum developers and educators in designing learning media that are not only visually appealing but also pedagogically effective for the continued mastery of concepts (Richter & Kickmeier-Rust, 2025).

2 | BACKGROUND THEORY

This chapter highlights the theoretical concepts that guide the use of gamification in mobile applications for science education. It also includes a critical review of motivational and cognitive theories, a synthesis of the literature on game design features, and an evaluation of existing research gaps related to long-term knowledge retention. Gamification in science education is deeply embedded in Self-Determination Theory (SDT) and Constructivism. The theory postulates that learning becomes optimal when students' psychological needs for autonomy, competence, and connectedness are met. In the context of mobile apps, game features such as badges and leaderboards serve as external reinforcements while instant feedback and freedom to choose problem-solving strategies facilitate intrinsic motivation (Jihadillah, 2025; Smirani & Yamani, 2024). The constructivist perspective further emphasizes that knowledge is actively built through social interaction and direct engagement which is significantly enhanced by collaborative and immersive gamification learning environments (Zourmpakis *et al*., 2023).

From a cognitive point of view, the effectiveness of gamification is explained through Cognitive Load Theory where good instructional design can reduce unnecessary cognitive load (extraneous load) through gradual challenges and interactive visualizations. This mechanism helps students process abstract scientific concepts such as atomic structure or biological systems without overloading their working memory and thus support better understanding (Angub *et al*., 2025). In addition, the gamification features support "deferred concept retention" by pleasurable repetition with multisensory engagement empirically proven to improve long-term memory over conventional methods (Lutfi *et al*., 2023; Tanilong & Cheng, 2026). The integration of gamification into Mobile Learning (m-learning) creates a flexible and accessible learning ecosystem on-the-go which is crucial for maintaining continuity in student engagement across diverse demographic backgrounds. Gamified mobile apps enable personalization of learning as well as equitable access to quality materials even in remote schools (Abenes-Balbin *et al*., 2023; Maryani *et al*., 2025). However, literature confirms that success hinges heavily on design rather than mere pointification; mature pedagogical integration is required so that game features truly support purposes of science learning rather than mere entertainment (Diaz & Loñez, 2024; Saputra *et al*., 2025).

The use of gamification has been more than well documented in the literature, however, there are gaps in research about its long-term cognitive sustainability. Most studies focus on short-term engagement; meanwhile, the impact of gamification on science longitudinal knowledge retention has yet to be analyzed (Dewi *et al*., 2024; Pechenkina *et al*., 2017). This study attempts to fill these gaps by integrating a motivation and cognition theoretical framework to assess how particular mobile application features can be designed not only to elicit temporary interest but also generate permanent knowledge structures (Smirani & Yamani, 2024).

3 | METHOD

This study uses the Systematic Literature Review (SLR) method to identify, assess, and synthesize research results in a systematic and transparent manner (Snyder, 2019). The research procedure is guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standard to ensure objectivity (Page *et al.*, 2021). This design is qualitative-descriptive in nature and aims to build a strong theoretical basis regarding the integration of technology in science education (Xiao & Watson, 2017). The use of SLR allows for the discovery of research patterns and gaps that can be replicated by subsequent researchers (Haddaway *et al.*, 2022). The literature was collected through the Scopus database with a publication time range of 2020 to 2026 to ensure up-to-date data. The search strategy uses Boolean (AND, OR) operators with keywords such as "Gamification Mobile application in science education" and "Mobile Gamification in education" (Zainuddin *et al.*, 2020). Based on initial identification, 254 records were found (Bai *et al.*, 2020). This process is documented in stages to maintain the accuracy and completeness of the data in the review process (Osatuyi *et al.*, 2018).

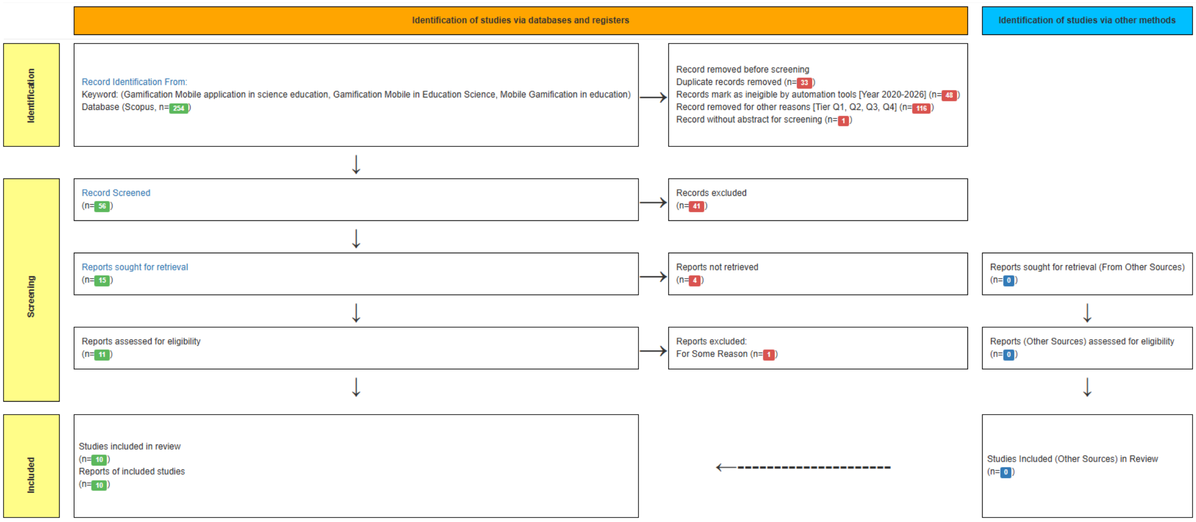

Figure 1. PRISMA Diagram Article Selection Flow

Inclusion criteria include Scopus-indexed empirical journal articles (Q1-Q4), relevant to educational gamification topics, and published in English or Indonesian (Sailer & Homner, 2020). In contrast, exclusion criteria include duplication (n=33), articles without full text, or non-scientific works (Kouhizadeh *et al.*, 2020). The application of these criteria aims to ensure that only valid and credible scientific sources are analyzed in this study (Donthu *et al.*, 2021). Selection is carried out systematically through four stages: identification, title/abstract screening, full-text feasibility test, and final inclusion (Cabactulan *et al.*, 2026). From the screening results, 11 articles were assessed for eligibility, and finally 10 articles were determined to be analyzed (Gao *et al.*, 2020). All stages are visualized through the PRISMA flowchart to show the number of articles received and issued transparently (Tayal & Rajagopal, 2024).

Data from 10 selected articles were extracted based on variables such as author name, method, and key findings (Linnenluecke *et al.*, 2019). Data analysis uses a qualitative synthesis approach to identify key themes related to the effectiveness of gamification in improving science literacy (Subhash & Cudney, 2018). The results of the analysis are compiled in the form of tables and narratives to describe the development of science (Baig & Yadegaridehkordi, 2023). The validity of the research is maintained with strict documentation of the selection process according to the PRISMA protocol (Rethlefsen *et al.*, 2021). Reliability is strengthened through the use of consistent assessment criteria to minimize subjective bias during data extraction (Aromataris & Pearson, 2014). The use of reference management ensures scientific integrity and consistency of the findings produced (Kraus *et al.*, 2020).

4 | RESULTS AND DISCUSSION

4.1 Results

The literature selection procedure in this study was carried out systematically following the PRISMA 2020 protocol, which began with the identification of 254 records from the Scopus database. Through the initial screening stage, strict filtering was carried out which excluded duplication (n=33), articles outside the range of 2020-2026 (n=48), and articles outside the Q1-Q4 qualifications (n=116) to ensure academic validity. Of the 56 articles that went through title and abstract screening, 10 final articles were selected because they met the criteria as empirical studies that demonstrate the role of mobile gamification in science education.

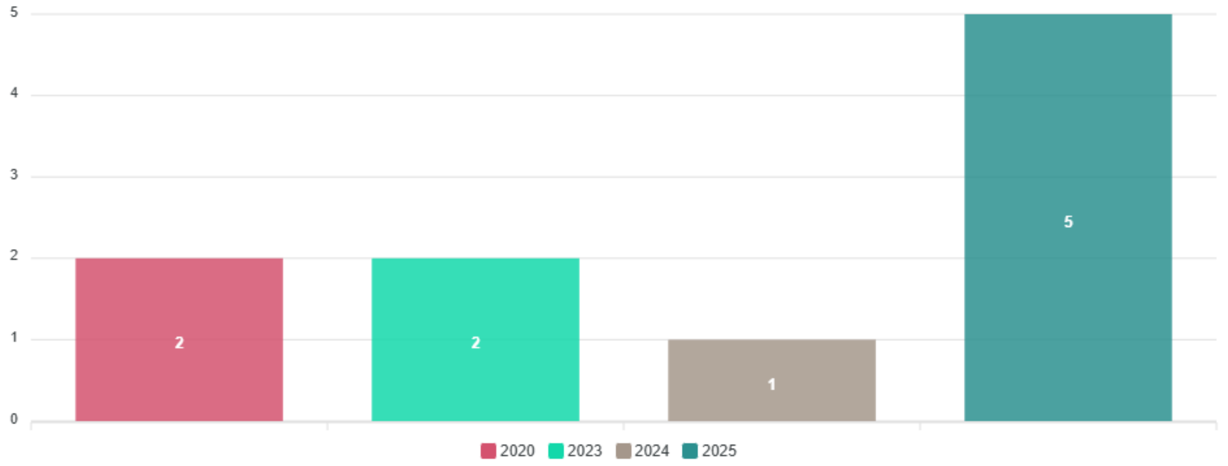

Figure 2. Year of Publication of the Article

The results of the analysis of the 10 articles showed that the most dominant motivation increase mechanism was triggered by the element of competition (*e.g*., leaderboards) and recognition (such as badges), as found in the studies of Piquer-Martinez *et al*. (2025) and Behmanesh *et al*. (2025). Meanwhile, the analysis of articles related to knowledge retention highlights that the use of interactive visualization and crisis simulation (as in AR and serious games) is highly effective in strengthening students' long-term memory by simplifying abstract science concepts (Cheng, 2023; Gaspar *et al*., 2020).

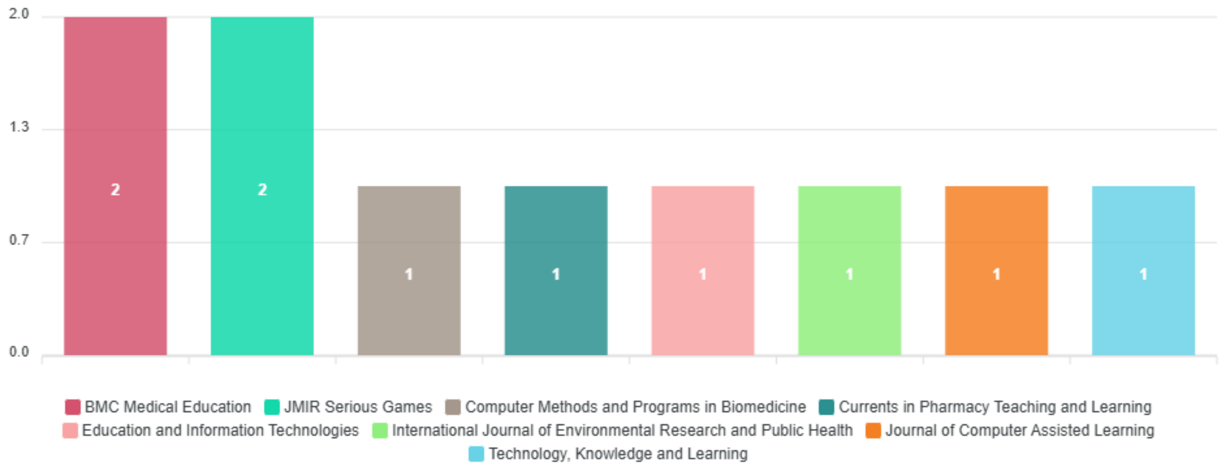

Figure 3. Journal Classification

Based on analysis of the 10 journal articles that have been selected, the following is an SLR table that was compiled to answer the research objectives regarding the role of mobile gamification in science education, motivation, knowledge retention, and strategies in environments with limited resources.

Table 1. Analysis of Mobile Gamification in Science Education

Author (Year)	Focus Area (Science/Health)	Motivation & Engagement Mechanism	Retention Mechanism & Long-Term Memory	The Most Effective Design Elements	Roles in Limited Environment/Key to Success
(Barkley *et al*., 2025)	Mental Health	Interactive narrative and meaningful choices in the scenario.	Iteration through feedback loops.	Branching decision points, Narrative, IVR.	Large-scale implementation in 6 African countries with low technology access.
(Al-Said, 2023)	General Education/Science	Integration of the role of teachers as motivators in m-learning.	Control perceptual behavior for continuous use.	Mobile app interactivity, Teacher support.	Overcome demotivation during isolation or distance learning.
(Bruggink *et al*., 2025)	Biology (Science)	Voluntary engagement through engagement loops.	A positive correlation between the duration of application use and the final value.	Content-customized quizzes, Dynamic elements.	Effectively improve learning outcomes in biology students in the upper year of the university.
(Cerqueira *et al*., 2025)	Oncology (Health)	Rewards system and self-navigating.	Health literacy through interactive information exploration.	Points, Quizzes, Rewards System.	Prototype design that prioritizes ease of patient self-management.
(Piquer-Martinez *et al*., 2025)	Pharmacy (Science)	A sense of achievement and learning autonomy.	Statistically significant improvement in academic performance.	Leaderboards, Badges, Competitive quizzes.	Comparison of cross-gender effectiveness in the mastery of pharmaceutical materials.
(Cheng, 2023)	Design & Technology	Visual immersion and visualization of abstract objects.	Reduction of external interference through a focus on AR media.	Augmented Reality (AR), 3D Visualization.	Strengthen competencies through immersion in the local environment.
(Ghaffarifar *et al*., 2024)	Medicine (ACLS)	Challenging and responsive instructional flows.	Mastery of procedural skills through mobile simulation.	Crisis simulation, Instant quiz, Clinical flow.	Mobile-accessible intensive medical training (ACLS).
(Behmanesh *et al*., 2025)	Midwifery (Science)	Competition between users and score gains.	Memory reinforcement against complex clinical protocols.	Scoring, Competition, Rewards.	Solves the problem of "quick forgetting" on dense medical materials.
(Zakaria *et al*., 2020)	Ethics Education	Tiered challenges and flexibility of the learning environment.	Game dynamics that adapt to the student's abilities.	Levels, Ranks, Interactive tasks.	Create a consistent learning flow.
(Gaspar *et*	Public Health	Community	Retention of	Visual	It can be run on a

al., 2020)	awareness and emotional engagement.	factual data about the pandemic through serious games.	narrative, Factual information of the WHO.	simple processor with low internet data consumption.

4.2 Discussion

This study emphasizes that mobile application gamification is not just a technological trend but a vital pedagogical instrument in science education. Based on systematic review, gamification's main role is to transform abstract and complex science concepts into concrete, interactive experiences. The most dominant motivation mechanisms are found in elements of competition such as leaderboards and rewards (Behmanesh *et al*., 2025; Piquer-Martinez *et al*., 2025), which significantly increase student engagement over conventional methods. This proves that the intrinsic and extrinsic impulses generated by game features are able to keep students' enthusiasm for learning for a longer duration. Design features such as augmented reality (AR) and procedural simulation were identified as the most effective in strengthening long-term memory and knowledge retention. By visualizing science data through 3D media (Cheng, 2023) or a fast feedback cycle (Barkley *et al*., 2025), students can consolidate information into long-term memory more efficiently. In line with Richter & Kickmeier-Rust (2025), this effectiveness depends on a balance of design that not only accentuates visual aesthetics but also the depth of the pedagogical content, ensuring sustained mastery of concepts without overloading the cognitive capacity of the student.

The review also found that gamification has great potential to be applied in school environments with limited resources. Findings from Barkley *et al*. (2025) and Gaspar *et al*. (2020) show that applications designed with low technical requirements (memory and data saving) are still capable of having a massive educational impact. This supports Maryani *et al*. (2025) that the limitations of physical infrastructure in the laboratory can be bridged through interactive mobile media that are able to simulate natural phenomena, so that students in remote areas still have access to high-quality science education. Although the effectiveness of gamification has been tested, a significant research gap has been found in the current literature. Most studies still focus on the short-term impact after application use, but very few have examined the long-term sustainability of knowledge retention (*e.g*., evaluation after 6 months or one year). In addition, there is limited literature on how the integration of mobile gamification affects students' cognitive load specifically on science topics that have a high level of difficulty, such as molecular genetics or quantum physics.

The integration of mobile gamification in the science curriculum provides a new theoretical contribution to educational technology by highlighting the importance of narrative elements and tiered challenges in the learning process. Practically, educators and curriculum developers are advised to prioritize design features that encourage autonomy and instant feedback. Thus, the resulting learning media is not only effective in increasing momentary motivation but also a powerful tool to ensure long-term knowledge retention in inclusive and adaptive science education. As a final implication, curriculum developers and educators should note that gamification success is not just about rewards but rather about challenging instructional design. Future research needs to explore more deeply about personalizing gamification features that can adapt to each student's learning pace. By closing the research gap, the role of mobile applications in science education can be optimized not only as a medium of attention but as the main instrument in producing deep and lasting mastery of science concepts.

5 | CONCLUSIONS AND FUTURE WORK

This Systematic Literature Review study concludes that mobile application gamification has a crucial role as a catalyst in increasing students' motivation and knowledge retention in science education through the integration of adaptive and interactive design features. The results of the synthesis of the selected literature show a consistent pattern in which competition features such as leaderboards and rewards are effective in triggering emotional engagement and intrinsic motivation, while simulation and Augmented Reality (AR) technologies have been shown to strengthen long-term memory through the visualization of abstract science concepts into more concrete forms. These findings answer the research question by affirming that pedagogical success depends not only on visual appeal but on a balance between the dynamics of the game and the depth of the science content that allows for continuous mastery of concepts, even in environments with limited resources. A key contribution of this review is mapping of effective mobile technology integration models to bridge the gap in physical laboratory facilities through digital media. Theoretically, this study enriched the educational technology literature by identifying a positive correlation between engagement loops in applications and significant improvement in students' academic performance. Although research gaps were found in the sustainability aspect of long-term retention, the results of this study provide a more systematic, integrated, and evidence-based understanding that pedagogically designed gamification strategies are able to transform science learning patterns to be more inclusive and qualitative.

Future research should focus on longitudinal studies that evaluate the sustainability of knowledge retention over extended periods (*e.g.*, 6-12 months post-intervention) to address the identified research gap. Additionally, investigations into how gamification features can be personalized to adapt to individual learning paces and cognitive loads, particularly for highly complex science topics such as molecular genetics or quantum physics, would provide valuable insights. Comparative studies examining the effectiveness of different gamification elements across diverse demographic and socioeconomic contexts would further strengthen the evidence base for implementing mobile gamification in resource-limited educational settings.

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How to cite this article: Prasetya, M. G. A., & Yasin, A. A. R. (2026). Comprehensive Analysis of the Role of Mobile Application Gamification in Science Education for Motivation and Knowledge Retention. *Journal Mobile Technologies (JMS)*, *4*(1), 25-33. https://doi.org/10.59431/jms.v4i1.709.