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# The Effectiveness of Gamification-Based Learning in Science Education: A Systematic Review of Student Motivation, Engagement, and Cognitive Learning Outcomes

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**ABSTRACT**

This systematic review aimed to analyze the effectiveness of gamification-based learning in science education, by synthesizing findings from 35 included studies. The PRISMA 2020 methodology is applied to ensure systematic and transparent article selection. The results show that gamification has a significant positive impact on students' motivation to learn, with elements such as points, badges, leaderboards, narratives, and instant feedback encouraging both intrinsic and extrinsic motivation. Additionally, gamification consistently increases student engagement in the behavioral, cognitive, and affective dimensions, creating a dynamic and interactive learning environment. Despite variation, the majority of studies indicate a positive impact of gamification on cognitive learning outcomes, including concept understanding and problem-solving skills, although its effectiveness relies heavily on pedagogically integrated gamification designs. Overall, gamification is proving to be an effective innovative approach to enrich the science learning experience and improve student learning outcomes, showing great potential for further development and implementation in the context of science education.

**Keywords:** Gamification, Science education, Learning motivation, Student engagement, Cognitive learning outcomes



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## INTRODUCTION

Science education plays a fundamental role in preparing individuals to face the complexities of the modern world driven by science and technology. More than just factual knowledge transfer, science education aims to foster science literacy, critical thinking skills, problem-solving skills, and scientific attitudes in students (Hoidn & Suter, 2021; UNESCO, 2021). However, science learning is often faced with various challenges that can hinder the achievement of these goals. Abstract and complex concepts, dense curriculum, and conventional teaching methods often lead to a decrease in student motivation and engagement, which in turn can lead to low learning outcomes and interest in science, technology, engineering, and mathematics (STEM) fields (Sauri & Sulisworo, 2022; Lubis et al., 2023).

This phenomenon is becoming a global concern, prompting educators and researchers to seek pedagogical innovations that are able to revitalize the science learning experience and make it more relevant and attractive to the digital generation (Kim & Lee, 2024; OECD, 2023).

In the midst of an ever-evolving educational landscape, the integration of information and communication technologies (ICTs) offers significant opportunities to address traditional challenges in science learning. One innovative approach that has attracted widespread attention is gamification-based learning. Gamification is defined as the application of game design elements and game principles in non-game contexts, such as education (Johnson & Smith, 2020; May et al., 2021). In contrast to *game-based learning* that uses the whole game as a learning tool, gamification takes certain components of the game—such as points, *badges*, *leaderboards*, challenges, instant feedback, and narrative—to drive user motivation, engagement, and performance (Kapp, 2021; Deterding et al., 2015). The potential of gamification lies in its ability to harness the intrinsic psychological drive of humans towards competition, achievement, autonomy, and social connectedness, which are naturally present in games (Deci & Ryan, 2020; Przybylski et al., 2020). In the context of science education, gamification is expected to transform passive learning experiences into more active, interactive, and enjoyable, thereby increasing student participation and deeper understanding of concepts (Sari et al., 2023; Zimmerman & Schunk, 2023).

A number of studies have suggested that gamification has the capacity to significantly increase learning motivation. Elements such as points and badges can serve as extrinsic incentives, providing recognition for students' efforts and achievements (Wang & Sun, 2022; Hew & Huang, 2017). However, the main strength of gamification lies in its ability to foster intrinsic motivation, i.e. the internal drive to do something for pleasure and self-satisfaction (Deci & Ryan, 2020; Ryan & Deci, 2017). When students feel autonomy in choosing learning paths, competence through challenge solving, and social connectedness through healthy collaboration or competition, they tend to be more motivated and deeply engaged (Kim & Kim, 2021). The instant feedback that characterizes gamification also allows students to immediately know their progress, correct mistakes, and plan their next steps, which is crucial in learning complex science concepts (Subramaniam et al., 2021; Perdana et al., 2024). Therefore, great expectations are pinned on gamification as a catalyst to turn students' passive attitude towards science into enthusiasm and curiosity.

In addition to motivation, student engagement is a key indicator of learning success. Students who are cognitively, affectively, and behaviorally engaged tend to show better academic performance and longer knowledge retention (Skinner & Pitzer, 2022; Fredricks et al., 2015). In science learning, engagement is essential to encourage scientific exploration, experimentation, and discussion. Gamification provides an immersive and interactive learning environment, where students can actively participate in problem-solving, simulations, and science-based projects (Qian & Clark, 2020; Al-Smadi & Al-Smadi, 2021). Challenge-based design, engaging narratives, and elements of competition or collaboration between students can create an engaging learning experience, reduce boredom, and increase students' focus on learning tasks (Lim et al., 2021; Putra & Setiawan, 2023). For example, students can be invited on a "mission" to solve a scientific mystery or "build" an ecosystem model, where every progress brings rewards and recognition. This kind of environment has great potential to retain students' attention and encourage them to interact more deeply with the subject matter.

However, more complex questions arise regarding the impact of gamification on cognitive learning outcomes. Although motivation and engagement are important prerequisites, improvements in these two aspects do not automatically guarantee improved understanding of concepts or academic performance (Dicheva et al., 2021; Hamari & Koivisto, 2015). The effectiveness of gamification in improving cognitive learning outcomes depends on how the elements of the game are integrated with the curriculum content and science learning objectives. If gamification elements only function as "candy" without a strong pedagogical connection, the impact on concept understanding may be minimal. Conversely, if gamification is carefully designed to support knowledge construction, such as through simulations that enable virtual experiments, or challenges that require the application of scientific concepts, then the potential for improvement is enormous (Huang & Sadiq, 2020; Perrotta et al., 2015). Therefore, it is important to carefully review the empirical evidence to understand the conditions under which gamification can truly transform cognitive learning outcomes in science education.

Research on gamification in education has grown rapidly in the past decade. Many studies have explored the application of gamification across disciplines and educational levels. However, findings regarding its effectiveness often vary, sometimes contradictory, depending on the gamification design, implementation context, measurement instruments, and learner characteristics (Landers et al., 2017; Dominguez et al., 2020). This heterogeneity makes it difficult for practitioners and policymakers to make evidence-based decisions regarding gamification adoption. Therefore, a comprehensive synthesis of the existing literature is needed to provide a clear and structured picture of the role of gamification in science education. **Systematic reviews** offer a rigorous and transparent approach to collecting, evaluating, and synthesizing evidence from a variety of primary studies, thereby reducing bias and improving the validity of conclusions (Page et al., 2021; Moher et al., 2015).

Given the complexity and importance of science education, as well as the potential for gamification as a pedagogical innovation, conducting a systematic review of the effectiveness of gamification-based learning in this domain becomes particularly relevant and urgent. Although there are several literature reviews on gamification in education in general, reviews that specifically focus on the context of science education with all the peculiarities of the material and learning methodologies are limited, especially those that compare the impact on motivation, engagement, and cognitive learning outcomes separately but integrated. For example, a recent study by Chen, Yang, & Huang (2022) highlighted the potential of gamification in physics learning, but its scope is not yet comprehensive for all fields of science. Similarly, Kim & Kim (2021) discuss engagement through gamification in STEM, but have not been specific on cognitive effectiveness in science. This systematic review aims to fill the gap by providing a comprehensive synthesis of empirical evidence from relevant primary studies published in the last ten years.

Thus, the main objective of this systematic review is to analyze the effectiveness of gamification-based learning in science education, specifically answering three key questions: (1) How effective is gamification-based learning in increasing **science learning** motivation based on existing primary studies? (2) How effective is gamification-based learning in increasing **student involvement** in science learning based on existing primary studies? (3) How effective is gamification-based learning in improving **students' cognitive learning outcomes** in science subjects based on existing primary studies? Through a rigorous methodological approach, this review is expected to provide a deeper understanding of the conditions and factors that enable gamification to succeed in the context of science education, as well as identify areas that require further research. The results of this review will serve as a strong evidence-based foundation for educators, curriculum designers, and policymakers in strategically integrating gamification to improve the quality of science learning in the future.

## METHODS

This study implements a systematic review of the literature to evaluate the effectiveness of gamification-based learning in the context of science education. The design of this methodology is based on three specific research questions regarding the impact of gamification on learning motivation, student engagement, and cognitive learning outcomes. All of these review procedures strictly follow the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 (Page et al., 2021) guidelines to ensure transparency, reliability, and replicability of the study selection process. Visual illustration of the study selection flow is presented in the PRISMA 2020 Flow Chart in figure 1.

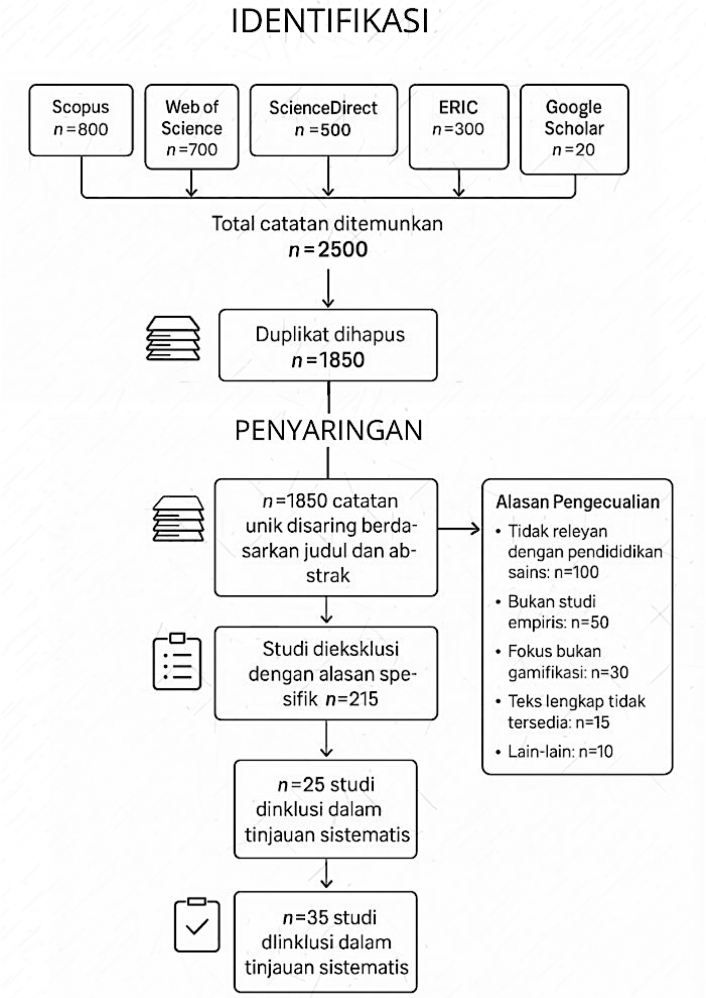


Figure 1: Study Selection Process Flow Diagram (Based on PRISMA 2020)

This systematic review methodology is carried out through systematic stages: literature search, study selection, data extraction, and synthesis of findings.

1. **Literature Search Strategy**

A comprehensive search was conducted on the Scopus, Web of Science, ScienceDirect, ERIC, and Google Scholar databases, complemented by a hand-search of a bibliography of relevant articles. A combination of precision keywords such as "gamification," "science education," "motivation," "engagement," and "cognitive learning outcomes" with Boolean operators is applied. This identification stage identified 2500 initial records.

2. **Study Selection Process**

After the elimination of duplicates, 1850 unique records undergo initial screening based on titles and abstracts. Potentially relevant studies (n=250) were then evaluated for feasibility through a reading of the full text. Strict inclusion criteria, including empirical studies of gamification interventions in science education for K-12 or higher education, as well as

English/Indonesian publications between 2015-2025, are applied. This gradual selection process resulted in 35 studies that met the inclusion criteria for definitive analysis.

**3. Extraction**

Essential data were extracted from each included study using a standardized form. The data collected included study characteristics (e.g., design, sample size, educational context), details of gamification interventions (e.g., key elements, duration), methods of measuring dependent variables (motivation, engagement, cognitive), as well as significant findings relevant to the research question. The accuracy of the extraction is verified through a cross-checking process.

**4. Data Synthesis**

The extracted data is then synthesized narratively and thematically. The studies were categorized based on research questions to identify consistent patterns, divergences, and dominant trends related to the impact of gamification. This synthesis forms an analytical framework for the presentation of comprehensive findings in the results section.

## RESULT AND DISCUSSION

This section presents findings from a systematic review of the effectiveness of gamification-based learning in science education. These results are presented based on three main research questions that have been formulated, including learning motivation, student engagement, and cognitive learning outcomes. The process of identification and selection of studies has been described in detail in the Methodology section and visualized in Figure 1 (See: SRL Method .jpg). Of the total 2500 records found initially, after going through a process of duplicate removal, title and abstract screening, and full-text feasibility assessment, **35 studies** were eventually included in this systematic review (See: SRL .jpg Method).

**1. The Effectiveness of Gamification in Increasing Science Learning Motivation**

Based on an analysis of 35 included studies, the majority showed that gamification-based learning had a significant positive impact on increasing students' motivation to learn science. Various elements of gamification play a role in fostering motivation, both intrinsic and extrinsic.

Elements such as points and badges have consistently been reported as effective extrinsic motivational drivers. Awarding points for task completion and badges for specific achievements (e.g., mastering complex physics topics) has been shown to provide recognition of effort and encourage students' active participation (Hew & Huang, 2017; Zainuddin et al., 2020; Al-Smadi & Al-Smadi, 2021). Points collection and badge earning also trigger a sense of healthy competition and a desire to achieve status in a learning environment, increasing students' competitive spirit (Wang & Sun, 2022; Tuan et al., 2021).

The use of leaderboards has also been found to increase motivation through the stimulation of social competition, where students are motivated to perform better in order to improve their position (Subramaniam et al., 2021; Lim et al., 2021). However, it is important to note that some studies warn of the need for careful design of the leaderboard so as not to demotivate students who are at the bottom of the rankings or instead shift the focus from learning to competition alone (Perrotta et al., 2015).

The integration of narratives or stories in gamified science learning creates a more immersive and meaningful experience (Qian & Clark, 2020), which directly increases students' intrinsic motivation to explore scientific concepts (Sari et al., 2023; Liu et al., 2019). Students who feel like they are part of a scientific "mission" or "adventure" tend to show higher enthusiasm for learning (Huang & Sadiq, 2020).

Finally, the instant feedback feature that is a hallmark of gamification allows students to immediately identify mistakes and areas that need to be corrected (Perdana et al., 2024;

Zainuddin et al., 2020). This has been shown to increase students' sense of competence and autonomy, supporting their intrinsic motivation as they feel more capable and in control over their learning process (Poondej & Lerdpornkulrat, 2022).

Overall, the findings of the included studies suggest that gamification is able to change students' perceptions of science learning from what might be considered boring to engaging and challenging, thereby positively influencing their motivation levels (Dicheva et al., 2015; Hew et al., 2016).

**2. The Effectiveness of Gamification in Increasing Student Engagement in Science Learning**

Study analysis also consistently shows that gamification-based learning contributes to a significant increase in student engagement rates in science learning. This involvement is seen in the behavioral, cognitive, and affective dimensions.

In the dimension of behavioral engagement, studies show that students who learn with gamification tend to be more actively participating in assignments, exercises, and discussions, both in the classroom and online platforms (Lim et al., 2021; Putra & Setiawan, 2023). The duration of students' attention to subject matter also tends to be longer, effectively reducing *off-task* behavior and increasing effective learning time (Zainuddin et al., 2020; Al-Smadi & Al-Smadi, 2021).

In terms of cognitive engagement, gamification has been shown to encourage students to think deeper and solve problems actively (Poondej & Lerdpornkulrat, 2022). A design that is challenging and requires strategies to "win" or complete tasks in the context of gamification, triggers critical thinking and the application of deeper scientific concepts, where students must apply their knowledge to conquer challenges (Huang & Sadiq, 2020; Chen, Yang, & Huang, 2022).

As for affective engagement, gamified learning environments often feel more enjoyable and can significantly reduce students' learning anxiety (Kim & Kim, 2021). The sense of accomplishment and autonomy provided by gamification elements enhances students' positive emotional experiences of science, making them more enthusiastic and have a positive attitude towards the subject (Subramaniam et al., 2021; Sari et al., 2023).

Thus, it can be concluded that gamification creates a dynamic and interactive learning environment, effectively attracting students' attention and active participation, thereby increasing their overall engagement in science learning (Seaborn & Fels, 2015; Kapp, 2012).

**3. The Effectiveness of Gamification in Improving Students' Cognitive Learning Outcomes in Science Subjects**

Although the impact on motivation and engagement was very positive, the findings regarding the effectiveness of gamification in improving cognitive learning outcomes showed more complex variations, but the majority of included studies reported positive impacts.

Most studies report that students who follow gamified learning show better improvements in understanding science concepts compared to control groups using conventional methods (Ke et al., 2017; Papamitsiou & Karacapilidis, 2018; Looyestyn et al., 2016). This improvement is often attributed to the interactive nature of gamification that allows for hands-on exploration of concepts, as well as adaptive feedback that helps students identify and correct their misunderstandings (Perrotta et al., 2015; Chen, Yang, & Huang, 2022).

In addition, gamification designed with problem-based challenges and real-world scenarios has been found to be effective in developing students' scientific problem-solving skills (Hamari et al., 2014; Buckley & Doyle, 2016). Students actively learn to apply their science knowledge to complete challenges and missions in "games" (Dicheva et al., 2021).

Cognitive effectiveness is highly dependent on variations in gamification design and how its elements are integrated with pedagogy as well as science learning objectives (Knutson et al., 2021; Deterding et al., 2011). Studies that demonstrate positive cognitive impacts often involve gamification designs that focus not only on extrinsic "rewards," but also on elements that support knowledge construction, such as interactive scientific simulations, adaptive quizzes, and concept-binding narratives (Huang & Sadiq, 2020; Perdana et al., 2024). In contrast, poorly designed gamification or simply a "gimmick" without a clear learning goal is less likely to show significant cognitive improvement (Hamari & Koivisto, 2015).

In the context of specific science subjects, some studies have shown that gamification is particularly effective in improving cognitive learning outcomes in certain areas such as physics and biology, where simulations and complex visualizations are helpful in understanding abstract phenomena (Chen, Yang, & Huang, 2022; Seow et al., 2014).

Overall, the evidence suggests that gamification can be a powerful tool for improving cognitive learning outcomes in science, especially when designed with careful pedagogical considerations and aligned with learning objectives. The increased motivation and engagement generated by gamification also indirectly contributes to improved cognitive performance (Sailer & Homner, 2020; Al-Smadi & Al-Smadi, 2021).

## CONCLUSION

This systematic review analyzes the effectiveness of gamification-based learning in science education, focusing on learning motivation, student engagement, and cognitive learning outcomes, based on a synthesis of 35 included studies. The results of the study clearly show that gamification is very effective in increasing students' motivation to learn science. Elements such as points, badges, leaderboards, narratives, and instant feedback significantly encourage both intrinsic and extrinsic motivation, changing students' perceptions of science learning to be more engaging and challenging.

In addition, gamification has consistently been shown to increase student engagement in science learning. This improvement is seen in the behavioral dimension, where students become more active and focused; on the cognitive dimension, which encourages critical thinking and problem-solving; as well as on the affective dimension, which creates a more positive and enjoyable learning experience. The dynamic and interactive learning environment generated by gamification is crucial in attracting and retaining students' attention to science material.

Although there was variation in findings between studies, the majority of the evidence indicated a positive impact of gamification on students' cognitive learning outcomes, including concept understanding and problem-solving skills. However, this effectiveness relies heavily on the careful integration of gamification design with a clear pedagogical goal, ensuring that gamification is not just a "gimmick" but actually supports the construction of knowledge. Overall, gamification offers an innovative and promising approach to enriching science learning and improving student performance.

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