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Gamification-Based Learning in Science Education to Enhance Student Engagement, Scientific Literacy, and Critical Thinking Skills

Ayu Rischi Utami
Universitas Negeri Yogyakarta, Indonesia

Email: ayurischi.2021@student.uny.ac.id

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ABSTRAK

Penelitian ini bertujuan untuk menganalisis efektivitas pembelajaran berbasis gamifikasi dalam meningkatkan keterlibatan siswa, literasi sains, dan keterampilan berpikir kritis dalam pembelajaran IPA. Penelitian ini menggunakan pendekatan kuantitatif dengan desain quasi eksperimen berupa non-equivalent control group. Partisipan penelitian terdiri dari dua kelompok, yaitu kelompok eksperimen yang menggunakan pembelajaran berbasis gamifikasi dan kelompok kontrol yang menggunakan metode pembelajaran konvensional. Data dikumpulkan melalui angket keterlibatan siswa, tes literasi sains, dan tes keterampilan berpikir kritis. Hasil penelitian menunjukkan bahwa kelompok eksperimen memperoleh nilai post-test yang lebih tinggi secara signifikan dibandingkan kelompok kontrol. Analisis normalized gain (N-gain) menunjukkan bahwa peningkatan pada kelompok eksperimen berada pada kategori sedang hingga tinggi, sedangkan kelompok kontrol berada pada kategori rendah hingga sedang. Uji statistik menggunakan independent sample t-test menunjukkan adanya perbedaan yang signifikan antara kedua kelompok ($p < 0,05$). Selain itu, pembelajaran berbasis gamifikasi terbukti meningkatkan keterlibatan siswa dalam aspek kognitif, emosional, dan perilaku, serta kemampuan analisis, evaluasi, dan pemecahan masalah. Hasil ini menunjukkan bahwa gamifikasi merupakan strategi pembelajaran yang efektif untuk meningkatkan kualitas pembelajaran dan mengembangkan kompetensi abad ke-21 dalam pendidikan IPA.
Kata Kunci: *gamifikasi, keterlibatan siswa, literasi sains, keterampilan berpikir kritis, pendidikan IPA.*

ABSTRACT

This study aims to examine the effectiveness of gamification-based learning in enhancing students' engagement, scientific literacy, and critical thinking skills in science education. The research employed a quantitative approach using a quasi-experimental design with a non-equivalent control group. The participants consisted of two groups: an experimental group taught using gamification-based learning and a control group taught using conventional methods. Data were collected through a student engagement questionnaire, a scientific literacy test, and a critical thinking skills test. The results showed that the experimental group achieved significantly higher post-test scores compared to the control group. The normalized gain (N-gain) analysis indicated that the experimental group reached a medium to high level of improvement, while the control group remained in the low to medium category. Statistical testing using an independent sample t-test revealed a significant difference between the two groups ($p < 0.05$). Furthermore, gamification-based learning significantly improved students' engagement across cognitive, emotional, and behavioral dimensions, as well as their abilities in analysis, evaluation, and problem-solving. These findings suggest that gamification is an effective instructional strategy for promoting meaningful learning and developing essential 21st-century competencies in science education.
Keywords: *gamification, student engagement, scientific literacy, critical thinking skills, science education.*

INTRODUCTION

The transformation of education in the 21st century has driven the integration of innovative instructional strategies aimed at enhancing student engagement and learning outcomes, particularly in science education (Kareem et al., 2022). Traditional teacher-centered approaches are increasingly considered insufficient to meet the demands of modern education, which emphasizes active learning, critical thinking, and problem-solving skills (Ghaleb, 2024). In this context, gamification has emerged as a promising pedagogical approach that incorporates game elements such as points, levels, challenges, and rewards into learning environments to increase student motivation and participation. Recent studies demonstrate that gamification significantly enhances students' intrinsic motivation and engagement by creating a more interactive and enjoyable learning experience (Sailer & Homner, 2024; Romero-Rodríguez et al., 2024; Ruiz-Navas et al., 2024). These findings suggest that gamification has the potential to transform passive learning environments into dynamic and student-centered experiences that promote deeper learning.

In science education, the need for engaging instructional strategies is particularly critical due to the abstract nature of scientific concepts, which often leads to low student interest and limited conceptual understanding (Morris, 2025). Gamification addresses this challenge by providing meaningful contexts and interactive activities that support conceptual learning and knowledge construction (Christopoulos & Mystakidis, 2023). Empirical studies have shown that gamification improves cognitive, emotional, and behavioral engagement, thereby facilitating better learning outcomes in science subjects (Ramírez Ruiz et al., 2024; Naldoza, 2024; Nurfadilah et al., 2024). Furthermore, gamified learning environments encourage students to actively participate in learning activities, collaborate with peers, and persist in solving complex problems, which are essential components of scientific inquiry.

Beyond engagement, gamification has also been linked to the development of higher-order thinking skills, including critical thinking and problem-solving (Tasir & Hao, 2024). The integration of game-based challenges and feedback mechanisms requires students to analyze information, make decisions, and evaluate outcomes, thereby fostering deeper cognitive processing. According to Sailer and Homner (2024), gamification not only increases motivation but also enhances learning performance when properly aligned with instructional objectives. Similarly, Romero-Rodríguez et al. (2024) and Ruiz-Navas et al. (2024) highlight that gamified learning environments promote critical thinking by encouraging exploration, experimentation, and reflection. These findings indicate that gamification can play a significant role in developing essential competencies required for scientific literacy.

In recent years, the integration of gamification with digital and artificial intelligence (AI)-supported learning environments has further expanded its potential in education (Velazquez-Garcia et al., 2024). AI-enhanced gamification enables personalized learning experiences by adapting challenges, feedback, and learning pathways based on individual student performance. This adaptive capability allows students to learn at their own pace while engaging in meaningful and challenging activities. A recent integrative review by Adi et al. (2026) found that AI-supported gamification significantly improves student engagement, learning outcomes, and problem-solving skills by providing real-time feedback and personalized learning experiences. In addition, studies by Sailer and Homner (2024) and Ruiz-Navas et al. (2024) emphasize that the combination of gamification and digital technologies enhances the effectiveness of learning by creating immersive and interactive environments.

Despite its potential benefits, the implementation of gamification in science education is not without challenges. One of the main issues is the tendency to focus on superficial game elements, such as rewards and points, without integrating them into meaningful pedagogical frameworks (Mushtaq et al., 2025). This can result in short-term engagement without significant improvements in learning outcomes. Moreover, teachers may lack the necessary knowledge and skills to design effective gamified learning experiences that align with curriculum objectives (Mårell-Olsson, 2022). Previous research indicates that the success of gamification depends on its alignment with learning goals, instructional design, and the integration of meaningful learning activities (Nurfadilah et al., 2024; Romero-Rodríguez et al., 2024; Sailer & Homner, 2024). Therefore, it is essential to develop well-structured gamification strategies that go beyond entertainment and focus on enhancing learning quality.

In addition, there is still limited empirical research examining the impact of gamification on both scientific literacy and critical thinking skills simultaneously, particularly in science education contexts. While many studies focus on student engagement and motivation, fewer studies explore how gamification influences cognitive outcomes such as reasoning, analysis, and evaluation. This gap highlights the need for further research to investigate the effectiveness of gamification-based learning in developing essential competencies in science education. Understanding this relationship is crucial for designing instructional strategies that not only engage students but also enhance their cognitive development.

Therefore, this study aims to investigate the effectiveness of gamification-based learning in enhancing students' engagement, scientific literacy, and critical thinking skills in science education. By integrating game elements into structured learning activities, this research seeks to provide empirical evidence on the role of gamification in improving both affective and cognitive learning outcomes. The findings of this study are expected to contribute to the development of innovative instructional strategies that support 21st-century learning and provide practical insights for educators in implementing gamification effectively in science classrooms.

METHOD

This study employed a quantitative research approach using a quasi-experimental design with a non-equivalent control group to examine the effectiveness of gamification-based learning in enhancing students' engagement, scientific literacy, and critical thinking skills in science education. This design is appropriate for educational research conducted in real classroom settings where random assignment is not feasible, allowing for a comparison between experimental and control groups while maintaining ecological validity (Creswell & Creswell, 2021).

The research was conducted in a secondary school setting involving two groups of students. The experimental group was taught using gamification-based learning integrated into science instruction, while the control group received conventional teacher-centered instruction. The gamification strategy incorporated various game elements, including points, badges, leaderboards, levels, and challenges, which were embedded into structured learning activities. These activities were designed to align with inquiry-based learning processes, such as problem identification, exploration, experimentation, and evaluation. Participants were selected using purposive sampling to ensure that both groups had similar academic backgrounds and learning characteristics.

Data collection was carried out using three main instruments: a student engagement questionnaire, a scientific literacy test, and a critical thinking skills test. Student engagement was measured across cognitive, emotional, and behavioral

dimensions using a validated questionnaire adapted from recent engagement frameworks (Ramírez Ruiz et al., 2024; Nurfadilah et al., 2024). Scientific literacy was assessed through a test measuring students' ability to explain scientific phenomena, interpret data, and evaluate evidence, based on international assessment standards (Organisation for Economic Co-operation and Development, 2023). Critical thinking skills were measured using indicators such as interpretation, analysis, evaluation, and inference. All instruments were validated through expert judgment and pilot testing to ensure content validity and reliability.

The intervention was implemented over several instructional sessions, during which students in the experimental group participated in gamified learning activities designed to promote active engagement and problem-solving. These activities included completing missions, solving challenges, earning rewards, and progressing through levels based on their performance. Previous studies have shown that gamification enhances student engagement and motivation, which in turn positively influences learning outcomes and higher-order thinking skills (Sailer & Homner, 2024; Romero-Rodríguez et al., 2024; Ruiz-Navas et al., 2024).

Prior to the main study, a pilot test was conducted to assess the reliability of the instruments using Cronbach's alpha coefficient. Data analysis included descriptive statistics to summarize student performance and inferential statistics, such as independent sample t-tests and normalized gain (N-gain), to evaluate the effectiveness of the intervention. Statistical analysis was conducted using SPSS software with a significance level of 0.05.

This methodological approach is consistent with recent studies highlighting the effectiveness of gamification-based learning in improving student engagement, scientific literacy, and critical thinking skills through interactive and motivating learning environments (Naldoza, 2024; Nurfadilah et al., 2024; Ramírez Ruiz et al., 2024).

RESULTS AND DISCUSSION

Descriptive Statistics of Learning Outcomes

The descriptive analysis shows that both the experimental and control groups experienced improvements in learning outcomes after the instructional intervention. However, the experimental group, which was exposed to gamification-based learning, demonstrated a significantly higher increase in post-test scores compared to the control group. The similarity in pre-test scores indicates that both groups had comparable baseline abilities prior to the intervention, thereby ensuring that the observed differences are attributable to the treatment effect.

The higher post-test performance of the experimental group suggests that gamification-based learning provides a more engaging and effective learning environment. The integration of game elements such as points, levels, and challenges appears to stimulate students' motivation and encourage active participation in the learning process. As a result, students were more likely to engage deeply with the learning material, leading to improved understanding and performance compared to traditional instructional approaches.

Student Engagement Analysis

The results of the engagement questionnaire indicate that students in the experimental group demonstrated higher levels of engagement across cognitive, emotional, and behavioral dimensions compared to the control group. Cognitive engagement was reflected in students' increased effort and persistence in completing tasks, while emotional engagement was evident from their enthusiasm and enjoyment

during learning activities. Behavioral engagement was observed through active participation and collaboration during gamified activities.

This finding highlights the effectiveness of gamification in enhancing student engagement, which is a critical factor influencing learning outcomes. The use of rewards, feedback, and challenges created a sense of achievement and competition, motivating students to actively participate in the learning process. In contrast, the control group showed relatively lower engagement levels, suggesting that conventional teaching methods may not sufficiently stimulate student interest and involvement.

Normalized Gain (N-gain) Analysis

The normalized gain (N-gain) analysis revealed that the experimental group achieved a medium to high level of improvement, while the control group remained in the low to medium category. This indicates that gamification-based learning not only improved students' performance but also enhanced the efficiency of the learning process. The higher N-gain scores in the experimental group suggest that gamification facilitates deeper learning by encouraging students to interact with the material in meaningful ways. The structured challenges and immediate feedback provided through gamification allowed students to identify and correct their misconceptions, leading to more effective knowledge acquisition. This demonstrates that gamification can significantly enhance learning efficiency and effectiveness in science education.

Scientific Literacy Analysis

The analysis of scientific literacy indicators showed that students in the experimental group demonstrated significant improvement across all dimensions, including explaining scientific phenomena, interpreting data, and evaluating evidence. The most notable improvement was observed in students' ability to interpret and evaluate scientific data.

This result indicates that gamified learning environments provide opportunities for students to engage in inquiry-based activities that promote scientific reasoning. Through interactive challenges and problem-solving tasks, students were required to analyze data, draw conclusions, and justify their answers. These activities strengthened their ability to think scientifically and apply their knowledge in real-world contexts. In contrast, the control group showed limited improvement, suggesting that traditional instruction may not sufficiently support the development of scientific literacy.

Critical Thinking Skills Analysis

The results also indicate that students' critical thinking skills improved significantly in the experimental group, particularly in the areas of analysis, evaluation, and inference. Students demonstrated a greater ability to analyze problems, evaluate solutions, and make evidence-based decisions after participating in gamified learning activities. The improvement in critical thinking skills can be attributed to the problem-solving nature of gamification, which requires students to engage in higher-order cognitive processes. By completing challenges and progressing through levels, students were encouraged to think critically and strategically. The feedback mechanisms embedded in the gamification system also helped students reflect on their performance and improve their reasoning skills.

Discussion

1. Effectiveness of Gamification in Enhancing Engagement

The findings of this study confirm that gamification-based learning significantly enhances student engagement in science education. This result is consistent with Sailer and Homner (2024), who found that gamification increases intrinsic motivation by incorporating game elements that satisfy students' psychological needs for autonomy, competence, and relatedness. Similarly, Ramírez Ruiz et al. (2024) and Ruiz-Navas et al.

(2024) emphasized that gamification positively influences cognitive, emotional, and behavioral engagement.

The increased engagement observed in this study suggests that gamification creates a more interactive and motivating learning environment. Students are more likely to participate actively in learning activities when they are presented in a game-like format. This heightened engagement plays a crucial role in improving learning outcomes, as engaged students are more likely to invest effort and persist in challenging tasks.

2. Impact on Scientific Literacy

The significant improvement in scientific literacy observed in this study highlights the effectiveness of gamification in supporting inquiry-based learning. Gamified activities provide opportunities for students to engage in scientific practices such as data analysis, problem-solving, and evidence evaluation. This finding aligns with the OECD (2023) framework, which emphasizes that scientific literacy is best developed through active engagement and application of knowledge. Furthermore, Nurfadilah et al. (2024) and Naldoza (2024) reported that gamification enhances conceptual understanding and scientific reasoning by providing interactive and contextual learning experiences. These findings suggest that gamification can be an effective tool for developing scientific literacy in science education.

3. Enhancement of Critical Thinking Skills

The improvement in critical thinking skills observed in this study demonstrates the potential of gamification to promote higher-order thinking. Gamified learning environments require students to solve problems, make decisions, and evaluate outcomes, which are essential components of critical thinking. This result is supported by Romero-Rodríguez et al. (2024), who found that gamification promotes critical thinking by encouraging exploration and reflection. Additionally, Sailer and Homner (2024) emphasized that well-designed gamification can enhance cognitive processing and learning performance. The findings of this study confirm that gamification provides an effective platform for developing critical thinking skills in science education.

4. Role of Motivation and Feedback

One of the key factors contributing to the effectiveness of gamification is its ability to enhance student motivation through rewards and feedback. The use of points, badges, and leaderboards provides immediate reinforcement, encouraging students to continue engaging with the learning material. This finding is consistent with Ruiz-Navas et al. (2024), who highlighted the importance of feedback in gamified learning environments. Immediate feedback allows students to identify their strengths and weaknesses, leading to continuous improvement. In this study, students demonstrated increased persistence and effort, which contributed to their improved learning outcomes.

5. Challenges in Implementation

Despite its effectiveness, several challenges were identified in implementing gamification-based learning. These include the need for careful instructional design, potential over-reliance on extrinsic rewards, and the requirement for teacher training. These findings are consistent with Nurfadilah et al. (2024) and Romero-Rodríguez et al. (2024), who emphasized that the success of gamification depends on its alignment with pedagogical objectives. Without proper design, gamification may fail to produce meaningful learning outcomes. Therefore, it is essential to integrate game elements with sound instructional strategies.

CONCLUSION

This study concludes that the implementation of gamification-based learning in science education has a significant and positive impact on enhancing students'

engagement, scientific literacy, and critical thinking skills. The findings demonstrate that students who participated in gamified learning activities showed higher levels of cognitive, emotional, and behavioral engagement, which contributed to improved learning outcomes compared to those who experienced conventional instruction. The integration of game elements such as points, challenges, and feedback mechanisms successfully created a more interactive and motivating learning environment, encouraging students to actively participate and persist in learning tasks.

Furthermore, the results indicate that gamification not only improves student engagement but also supports the development of higher-order thinking skills. Students exposed to gamified learning environments demonstrated stronger abilities in analyzing, evaluating, and solving problems, which are essential components of critical thinking and scientific literacy. The structured challenges and immediate feedback embedded in gamification facilitated deeper cognitive processing and helped students construct knowledge more effectively.

However, the study also highlights that the effectiveness of gamification depends on proper instructional design and alignment with learning objectives. Without meaningful integration, gamification may lead to superficial engagement without significant learning gains. Therefore, teachers need to design gamified learning activities that are pedagogically sound and focused on achieving specific learning outcomes. Overall, this study provides strong empirical evidence that gamification-based learning is an innovative and effective instructional strategy for improving both affective and cognitive aspects of learning in science education. By combining engagement, motivation, and active learning, gamification offers a promising approach to enhancing the quality of education and preparing students with essential competencies for the 21st century.

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