International Journal of Trends in Mathematics Education Research
Vol. 7, No. 3 (2024), pp. 182-188
ISSN 2621-8488 (online)
DOI: https://doi.org/10.33122/ijtmer.v7i3.368

Review Article

Gamification in STEM Education: A Systematic Literature Review

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ABSTRACT

This study aims to assess the impact of gamification in STEM education by focusing on student motivation, engagement, and learning outcomes. Gamification, or the use of game elements in non-game contexts, is applied in STEM education to enhance more engaging and interactive learning experiences. The literature review is carried out in a narrative manner by analyzing relevant research in the last 10 years obtained from various databases, such as Google Scholar and IEEE Xplore. The results of the study show that gamification elements, such as leaderboards, points, and badges, are effective in increasing student motivation and engagement, especially in subjects that tend to be difficult. In addition, gamification plays an important role in the formation of collaborative skills through activities such as "escape rooms" and gamification-based project simulations. However, the implementation of gamification is faced with challenges, such as adaptation to the institutional context and the need for adequate design to sustain long-term impacts. This review recommends the implementation of planned gamification, contextual adjustments, and continuous evaluation to improve the effectiveness of gamification in STEM education. Thus, the results of this study provide guidance for educators in integrating gamification as a relevant and adaptive learning strategy in the modern education era.

Keywords: Gamification; STEM Education; Motivation; Student Engagement; Learning Outcomes

1. INTRODUCTION

Gamification in STEM education has become an increasingly important topic in efforts to increase student engagement and motivation. Research shows that the application of gamification is able to significantly improve students' STEM abilities and soft skills. A study by Wangi (2022) found that students who participated in gamification-based learning showed significant improvements in STEM abilities and soft skills compared to the control group that received conventional learning. These findings are in line with a meta-analysis by Kim and Castelli (2021) which revealed that increased study time and student participation contributed to better academic achievement. In addition, in online learning, Bennani et al. (2021) noted that gamification frameworks are increasingly being applied, with evidence of success in increasing cross-sector engagement in education. At the university level, Harrington and Mellors (2021) showed that gamification activities increase student engagement, participation, and retention, showing the benefits of gamification at various levels of education.

In the context of STEM education, the use of gamification elements such as educational robots also plays an important role in motivating and developing students' creativity. Chen et al. (2023) found that gamified educational robots assist students in solving problems and increasing motivation, signaling that the integration of gamification elements into learning content creates a more interactive learning experience. However, the implementation of gamification is not free from challenges. Suryatama (2023) highlighted the importance of designing effective game mechanics so that gamification does not distract students from learning objectives. On the other hand, Funa et al. (2021) show that there are challenges in the form of peer pressure and disorders that need to be overcome so that the motivation generated by gamification can have a long-term impact.

The study of gamification in STEM education has become relevant in facing learning challenges in the 21st century, especially because the application of game elements has been proven to be able to increase students' interest in subject matter that is often considered difficult or boring. Abdullah and Razak (2021) found that gamification increased students' interest and acceptance of the material, which ultimately supported more effective learning. Mulyanti (2023) also highlighted that the implementation of gamification-based flipped classrooms has a positive impact on student science learning outcomes, proving the benefits of gamification not only on motivation, but also on academic achievement. In addition, research shows that gamification serves as a tool to create an interactive and fun learning environment. Firdaus and Faisal (2021) noted that gamification increases motivation through providing positive feedback and recognition of

student achievements. This is especially relevant in STEM education, where students are often exposed to complex material. Elements such as points, badges, and rankings are proven to make students feel more engaged and excited about learning (Nurningtias & Majid, 2022). Budiyono et al. (2023) also showed that basic education students have a positive perception of gamification in STEAM education, indicating the importance of integrating gamification in STEM curricula.

Gamification brings great potential in STEM education, there are also challenges that need to be faced. Mei and Surat (2021) revealed that teachers' perceptions of gamification are diverse, especially in designing effective learning experiences. Educators need to understand the gamification elements that best suit the needs of students and their learning context. Research by Haryani et al. (2023) adds that the application of new technologies such as blockchain in gamification can bring innovative solutions, but requires a structured and planned approach. Therefore, this literature review is very important to understand the impact and challenges of implementing gamification in STEM education. With a deep understanding, it is hoped that gamification can be an effective tool in improving student motivation, engagement, and learning outcomes, answering the needs of relevant and useful STEM education.

Many studies have shown the potential of gamification in improving student motivation, engagement, and learning outcomes in STEM fields, some aspects of which are still not deeply understood. Existing studies show the effectiveness of gamification elements in specific contexts, but lack discussion on how the sustainability of motivation resulting from gamification can be optimally maintained and integrated in STEM curricula. In addition, research that specifically explores the challenges in the application of gamification, especially in the context of STEM education at various levels, is still limited. This gap requires more attention to understand the extent to which gamification supports not only students' academic achievement and technical skills, but also the collaboration and social learning abilities that are essential in the modern educational environment. Therefore, the research question (RQ) in this study is to explore the effectiveness of gamification in increasing student motivation and engagement in STEM education (RQ 1), its impact on skills and learning outcomes (RQ 2), and the challenges of its application in the STEM teaching process (RQ 3). In addition, this study will evaluate the potential of gamification in facilitating collaboration and social learning (RQ 4). By answering the questions of this research, it is hoped that the results of this study can provide comprehensive insights into the role of gamification in supporting STEM learning more effectively and sustainably.

Gamification

Gamification, or gamification in English, is a concept that adopts game elements into non-gaming contexts to improve user motivation, engagement, and experience. This definition includes the use of various game design components such as points, badges, and leaderboards in systems that are not directly related to the game, such as education, business, and marketing (Atmaja et al., 2020; Gerungan, 2023; Sany & Zikri, 2021). In the context of education, gamification has been proven effective in increasing students' interest in learning, with the application of game elements that make the learning process more fun and interactive (Syuhada, 2023; Guntara, 2021).

In the business world, gamification is used to improve the customer experience and maintain their loyalty. For example, in e-commerce, the application of gamification can be in the form of giving rewards to customers who meet certain conditions, which in turn can increase motivation to transact (Setiarso & Hidajat, 2020; Perkasa & Emanuel, 2020). In addition, gamification also serves as an effective marketing tool, where companies can collect data about user preferences through gamified interactions (Putri et al., 2022). Thus, gamification not only serves to increase user engagement, but also to provide valuable insights for companies in understanding their customer behavior. Furthermore, gamification has been applied in various fields, including health, tourism, and education. In education, for example, gamification can increase students' motivation to learn by creating an interesting and fun learning environment (Guntara, 2021; Khalid, 2023). In the tourism sector, gamification seeks to create a pleasant experience for tourists, while fulfilling educational and recreational goals (Gurning, 2023). Thus, gamification is a multifunctional approach and can be adapted to various contexts to achieve the desired results. Based on the explanation above, gamification is an innovative and effective method to increase motivation and engagement in various contexts. By integrating game elements into non-game systems, gamification can create a more engaging and satisfying experience for users, whether in education, business, or other fields (Atmaja et al., 2020; Marisa et al., 2022; Marisa et al., 2020).

STEM Education

STEM education, which is an acronym for *Science, Technology, Engineering, and Mathematics*, refers to an educational approach that integrates the four disciplines in the teaching and learning process. This concept aims to prepare students to face the challenges of the global economy and the rapid development of technology in the 21st century (Yuliana, 2023). STEM education is not only limited to teaching theory, but also emphasizes on practical application and the development of critical skills necessary in the world of work (Herlanti et al., 2022). One important aspect of STEM education is its ability to increase creativity and innovation among students. Research shows that the application of STEAM methods (which add art to STEM education) can enhance early childhood creativity, suggesting that the integration of disciplines can result in

more holistic and engaging learning (Wahyuningsih et al., 2019; Mariana et al., 2023). In addition, STEM education has also contributed to improving the quality of teachers and students in various countries, including Indonesia, Singapore, Australia, and the United States, all of which have adopted this approach to improve the quality of their education (Yuliana, 2023).

In Indonesia, STEM education is expected to help students develop skills that are relevant to industry needs, especially in the face of the industrial revolution era 4.0. Research shows that school readiness in implementing STEM education still needs to be improved, especially in terms of teacher training and the provision of adequate resources (Herlanti et al., 2022). Therefore, it is important for relevant parties to continue to support the development of STEM-based curricula, so that students can acquire the knowledge and skills necessary to compete at the global level. Thus, STEM education is an innovative and relevant approach in the context of modern education. By integrating science, technology, engineering, and mathematics, STEM education not only prepares students for careers in related fields, but also equips them with critical and creative thinking skills that are much needed in this ever-changing world (Yuliana, 2023; Herlanti et al., 2022).

2. RESEARCH METHODS

The research method in this study follows a systematic stage to identify, analyze, and synthesize research on gamification in STEM education. The process begins with a literature selection based on strict inclusion criteria; only peer-reviewed articles in the last 10 years that focused on gamification in STEM were considered. Articles that are irrelevant or unpublished in scientific journals are excluded. The literature was obtained from academic databases such as Google Scholar, Scopus, IEEE Xplore, and SpringerLink using keywords such as "gamification in STEM education" and "STEM student motivation" (Ortiz et al., 2016; Venter, 2020). Further selection is carried out by examining abstracts and keywords to ensure the suitability of the topic. Furthermore, the selected articles were analyzed descriptively based on the research method, population, and main findings. The data were then synthesized thematically, grouping studies based on research questions (RQs) such as the impact of gamification on student engagement and understanding of STEM concepts, as well as the effects of game elements such as leaderboards and rewards in increasing learning motivation (Andrade et al., 2020; Funa et al., 2021). The quality of the article is assessed from the transparency of the methodology and the validity of the data. The results of the synthesis were analyzed to highlight gaps in the literature and the potential application of gamification in STEM education. Limitations, such as limited article access or selection bias, are also discussed. This review aims to provide an in-depth understanding of the effectiveness of gamification in STEM education and provide recommendations for further research and implementation practices in STEM curricula (Ortiz-Rojas et al., 2019; Zhao et al., 2021).

3. RESULTS AND DISCUSSION

Based on the results of the selection of several relevant previous studies that have met the rules of inclusion and exclusion, 12 relevant articles can be reviewed in **Table 1**.

Table 1. Selection Results for Relevant Articles

Author and Year	Article Title	Research Results
Alhammad & Moreno (2018)	Gamification in software engineering education: A systematic mapping	Identify the potential and challenges of gamification in software engineering education with a focus on increasing student motivation and engagement.
Andrade et al. (2020)	Evaluating the effects of introducing three gamification elements in STEM educational software for secondary schools	Demonstrate increased student engagement and learning performance in the context of online physics through the use of points, badges, and rankings.
Funa, Guide, & Ricafort (2021)	Gamification in genetics: Effects of gamified instructional materials on the STEM students' intrinsic motivation	The application of gamification elements in genetics lessons increases students' intrinsic motivation, although gamification tends to be considered as extrinsic motivation.
Moral-Sánchez, Sánchez-Compaña, & Romero (2022)	Geometry with a STEM and gamification approach: A didactic experience in secondary education	The gamification approach to geometry lessons improves academic outcomes and student motivation in secondary education.
Ortiz, Chiluiza, & Valcke (2016)	Gamification in higher education and STEM: A systematic review of literature	Review the elements of gamification that are effective in improving student motivation and performance at the higher education level on STEM-related subjects.

Ortiz-Rojas, Chiluiza, & Valcke (2019)	Gamification through leaderboards: An empirical study in engineering education	Empirical studies found that leaderboards can improve student performance in engineering education without the significant interaction effect of mediating variables.
Pirker & Gutl (2015)	Educational gamified science simulations	Develop a constructivism-based gamification model that helps improve students' problem-solving abilities in science.
Sakulkueakulsuk et al. (2018)	Kids making AI: Integrating machine learning, gamification, and social context in STEM education	Integrating machine learning with gamification in STEM education, promoting collaborative learning relevant to the social context.
Sánchez-Martín et al. (2020)	Exit for success: Gamifying science and technology for university students using escape-room	Use escape room activities to increase engagement and develop students' specific and transversal competencies in STEM higher education.
Signori et al. (2018)	Gamification as an innovative method in the processes of learning in higher education institutions	Identify performance expectations as an important factor in the acceptance of gamification in higher education institutions.
Venter (2020)	Gamification in STEM programming courses: State of the art	Gamification on STEM programming courses shows increased student motivation, participation, and understanding in mastery of programming content.
Zhao et al. (2021)	An innovative multi-layer gamification framework for improved STEM learning experience	The multi-layer gamification model improves the learning experience and engagement of students in STEM subjects in European schools.

Based on the article above (Table 1), the discussion can be explained based on the research question below:

RQ 1: How Gamification Effectiveness Increases Student Motivation and Engagement in STEM Education

Gamification has been shown to increase student motivation and engagement, especially in STEM disciplines that are often considered difficult and unattractive by students. Research by Ortiz, Chiluiza, and Valcke (2016) found that the application of gamification elements such as leaderboards, badges, and points can motivate students at the higher education level. This study noted improvements in performance, goal orientation, and students' positive attitudes towards computer science-related subjects in the context of STEM education (Ortiz et al., 2016). A similar increase in motivation was also found in another study by Funa, Gabay, and Ricafort (2021), which stated that although gamification is often considered an extrinsic motivation, STEM students in genetics subjects showed a significant increase in intrinsic motivation. By utilizing the element of play in the learning management system, this study shows that gamification can also help students face negative behavior challenges such as excessive competition that has the potential to lower learning enthusiasm (Funa et al., 2021). Another research that supports these findings is a study conducted by Venter (2020), which emphasizes that gamification, particularly in STEM programming courses, increases student participation and interest in learning content. This study highlights the effectiveness of leaderboards, badges, and levels in improving students' programming knowledge and motivation to be more actively involved in the learning process (Venter, 2020).

RQ 2: How Gamification Impacts Improving Skills and Learning Outcomes in STEM Education

The use of gamification in STEM education not only increases motivation, but also has a direct impact on improving students' skills and learning outcomes. For example, research by Moral-Sánchez, Sánchez-Compaña, and Romero (2022) shows that the application of gamification approaches in geometry learning in secondary education contributes to improved academic outcomes, with all students successfully passing subjects that initially had a high failure rate (Moral-Sánchez et al., 2022). A parallel study also comes from the research of Andrade et al. (2020) which evaluated the influence of the three elements of gamification (points, badges, and rankings) in online physics lessons. The results showed an improvement in student engagement and learning performance, although motivation did not change significantly. However, the impact on the engagement and perception of the usefulness of educational programs suggests that gamification can make STEM learning more enjoyable and engaging for students (Andrade et al., 2020). Another study that supports the positive effects of gamification on learning outcomes is by Pirker and Gütl (2015), who developed a gamification model designed specifically for scientific simulation in constructivism-based STEM education. This model helps improve students' problem-solving abilities and understanding of conceptual models and formulas that are often abstract in science subjects (Pirker & Gütl, 2015).

RQ 3: How to Apply and Challenge Gamification in STEM Teaching

In addition to the benefits generated, the study also shows the challenges of implementing gamification in STEM teaching, especially related to the need for an approach that is more tailored to the context and characteristics of students. Research by Signori et al. (2018) identified that the implementation of gamification in higher education institutions must consider factors such as performance expectations and facility conditions that support gamification in order to make learning more effective (Signori et al., 2018). A study by Zhao et al. (2021) in the Horizon 2020 project also offers an innovative model for gamification application called N-EGM, which aims to address this challenge. This model provides solutions to adapt gamification functions to heterogeneous technological contexts, including support for personalization and advanced learning technologies. The application of this model in schools demonstrates its effectiveness in improving student learning experience and engagement, as well as improving students' understanding of STEM concepts (Zhao et al., 2021). Alhammad and Moreno (2018) also found that the application of gamification in the field of software engineering (SE) in higher education is still in its early stages. This study emphasizes the need for more detailed guidance on effective gamification elements in the context of SE and identifies various challenges such as implementation costs, selection of appropriate gamification elements, and controlling the impact of gamification on learning outcomes (Alhammad & Moreno, 2018).

RQ 4: How Gamification Improves Collaboration and Social Learning

Gamification has also been shown to be effective in improving collaboration and social learning in STEM educational environments. For example, research by Sánchez-Martín et al. (2020) explores the use of escape room activities as a gamification tool in science and technology learning in universities. These activities not only increase student engagement but also develop specific and transversal competencies and create a positive experience among students (Sánchez-Martín et al., 2020). An additional study by Sakulkueakulsuk et al. (2018) highlights a gamification-based education approach in Thailand that focuses on teaching machine learning and artificial intelligence through game-based challenges. Using this approach, students are introduced to project-based learning and collaboration that is relevant in a social context. The results of the study suggest that interdisciplinary learning can be enhanced by gamification, providing students with a deeper understanding of how technology can be applied to real-world problems (Sakulkueakulsuk et al., 2018).

4. CONCLUSION

Based on a literature review, gamification plays a significant role in supporting STEM learning, especially in improving student motivation, engagement, and skills. Gamification elements such as leaderboards, badges, and points show a consistent positive impact on student performance, especially in reinforcing understanding of science, technology, engineering, and math subjects that are often considered difficult. In addition, gamification has also been shown to be able to facilitate social and collaborative learning among students, which is increasingly relevant in the context of project-based education. While many benefits have been identified, the implementation of gamification in STEM education faces challenges such as the need for contextualization and proper design for its implementation to be effective at different levels of education. Several studies underscore the importance of planned strategies to overcome the limitations of facilities and costs, as well as the obstacles in integrating gamification technologies in diverse educational environments.

RECOMMENDATIONS

Based on these findings, several recommendations are suggested to optimize the application of gamification in STEM education. First, it is suggested that gamification be adjusted to the needs of students and the characteristics of each educational institution. A more personal and contextual approach is believed to increase the positive impact of gamification on student motivation and learning outcomes. Second, more specific implementation guidelines are needed for gamification elements in STEM curricula, especially in high-difficulty disciplines such as mathematics and physics. Third, the development of technology-based innovations that support social learning and collaboration, such as project-based activities and scientific simulations, is highly recommended to strengthen students' interdisciplinary competencies and problem-solving skills. Finally, a long-term evaluation of the impact of gamification in STEM education is also recommended to comprehensively understand its impact on learning outcomes and its contribution to the achievement of STEM competencies. With mature strategies and adaptations, gamification has the potential to be an innovative tool that enriches the learning experience and improves the quality of education in STEM fields.

ACKNOWLEDGEMENTS

The authors would like to thank all those who have helped in the process of completing this article so that it can be published in the journal.

AUTHOR'S CONTRIBUTIONS

The authors discussed the research results and contributed from the beginning to the finalization of the manuscript.

CONFLICT OF INTEREST

No conflicts of interest related to this article have been declared by the authors.

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