EDUMASPUL
JURNAL PENDIDIKAN
Vol. 8 – No. 1, year (2024), page 1480-1488
| ISSN 2548-8201 (Print) | 2580-0469) (Online) |

The Impact of Gamification on Problem Solving Skills in STEM Education: A Meta-analysis

Ellina Rienovita[1*], Arifin[2], Venty Sopacua[3,] , Wahyu Kumala sari[4], Bambang Mardi Sentosa[5], Mia Aina[6,] Hersiyati Palayukan[7], Tomi Apra Santosa[8]

[1] *Universitas Pendidikan Indonesia, Indonesia*
[2] *Universitas Pamulang, Indonesia*
[3]*Universitas Pattimura, Indonesia*
[5]*Universitas Islam Syekh Yusuf, Indonesia*
[6]*Universitas Jambi, Indonesia*
[7] *Universitas Kristen Indonesia Toraja, Indonesia*
[8]*Akademi Teknik Adikarya, Indonesia*
*Corresponding email:ellina_rienovita@upi.edu

Receive: 11/01/2024	***Accepted: 14/02/2024***	***Published: 01/03/2024***

Abstrak

Meta-analisis ini bertujuan untuk menyelidiki dampak gamifikasi terhadap kemampuan pemecahan masalah dalam pendidikan STEM. Penelitian ini menganalisis 16 studi yang membandingkan intervensi berbasis gamifikasi dengan metode pengajaran tradisional di pendidikan dasar dan menengah awal. Hasil penelitian menunjukkan gamifikasi memberikan efek positif terhadap kemampuan pemecahan masalah, dengan ukuran efek rata-rata tertimbang sebesar 1.28. Selain itu, analisis menunjukkan adanya heterogenitas yang signifikan antar studi, yang menunjukkan bahwa efektivitas gamifikasi bervariasi di berbagai konteks. Analisis moderator menunjukkan bahwa siswa sekolah dasar lebih diuntungkan dari intervensi berbasis gamifikasi daripada siswa sekolah menengah, tetapi gender tidak memiliki efek moderasi yang signifikan. Studi ini menyoroti manfaat potensial gamifikasi dalam meningkatkan kemampuan pemecahan masalah dalam pendidikan STEM, terutama untuk siswa sekolah dasar. Namun, temuan ini juga menunjukkan bahwa efektivitas gamifikasi mungkin bergantung pada berbagai faktor, seperti konteks spesifik dan demografi siswa, yang memerlukan penyelidikan lebih lanjut.

Kata Kunci: *Gamification; Pemecahan Masalah; STEM; Meta-analisis*

The Impact of Gamification on Problem Solving Skills in STEM Education: A Meta-analysis

Abstract

This meta-analysis aimed to investigate the impact of gamification on problem-solving skills in STEM education. The study analyzed 16 studies that compared gamification-based interventions with traditional teaching methods in primary and early secondary education. The results showed moderate positive effects of gamification on problem-solving skills, with a weighted mean effect size of 0.67. Additionally, the analysis revealed significant heterogeneity between studies, suggesting that the effectiveness of gamification varied

across different contexts. Moderator analyses indicated that primary school students benefited more from gamification-based interventions than secondary school students, but gender did not have a significant moderating effect. The study highlights the potential benefits of gamification in enhancing problem-solving skills in STEM education, particularly for primary school students. However, the findings also suggest that the effectiveness of gamification may depend on various factors, such as the specific context and student demographics, which warrants further investigation.

***Keywords**: Gamification; Troubleshooting; STEM; Meta-analysis*

Introduction

Science, Technology, Mathematics, and Engineering (STEM) education plays an important role in increasing people's capabilities and awareness of technology and innovation (Zhan et al., 2022; Asigigan & Samur, 2021; Zulyusri et al., 2023). In the era of globalization and industrial revolution 4.0 (Fradila et al., 2021; Nurtamam et al., 2023), STEM education has become highly relevant to prepare future generations to face the challenges and opportunities that come with technological advancements (Su, 2019; Rahman et al., 2023). Thus, STEM education not only helps students to understand the basic concepts of science and technology, but also helps them to develop skills needed in modern society, such as critical thinking, analysis, and problem solving skills (Roberts et al., 2018; Elfira et al., 2023; Rahman et al., 2023).

However, STEM education also faces some challenges in engaging students (Zulkifli et al., 2022). One of the main challenges is how to make these subjects more interesting and interactive for students, especially for students who do not have a strong interest or aptitude in these areas (Shahali et al., 2017); . Thus, STEM education should be able to integrate more interactive and playful elements, such as gamification, to increase students' awareness and interest in these subjects (Botia et al., 2015). Thus, STEM education can be more effective in increasing students' abilities and awareness, as well as preparing them for the challenges and opportunities that come with technological advancements (Glancy, & Moore, 2013; Rojas et al., 2019; Suharyat et al., 2022).

Gamification, a concept that integrates game design elements into non-game contexts, has gained significant traction in the educational sector (Saleem et al., 2022). This trend is driven by the need to enhance student engagement and motivation in learning processes. By incorporating elements such as rewards, competition, and progress tracking, gamification aims to create a more interactive and enjoyable learning environment (Ampong, 2020). This approach has been particularly effective in STEM education, where students often struggle to stay motivated due to the abstract and theoretical nature of the subject matter (Simões et al., 2013). By leveraging gamification, educators can make learning more accessible and enjoyable, ultimately leading to improved student outcomes and a more effective learning experience (Toda et al., 2019; Suharyat et al., 2022).

Gamification has been recognized as a powerful tool in enhancing problem-solving skills in STEM education. By incorporating game design elements into educational settings, gamification can increase student engagement and motivation, leading to improved learning outcomes (Júnior et al., 2019;Wangi et al., 2022) . Specifically, gamification can foster

critical thinking, creativity, and collaboration skills, all of which are essential for developing effective problem-solving strategies. Moreover, gamification can make complex STEM concepts more accessible and enjoyable, encouraging students to explore and experiment with different approaches to solve problems (Asigigan & Samur, 2021). This can lead to a deeper understanding of STEM principles and a greater confidence in applying them to real-world challenges.

The benefits of gamification in STEM education are multifaceted. For instance, gamification can enhance problem-solving skills by providing students with a sense of accomplishment and progression as they complete tasks and achieve milestones (Shchedrina et al., 2020). This can be particularly effective in STEM subjects where complex problems often require iterative and adaptive approaches. Additionally, gamification can promote a growth mindset, encouraging students to view challenges as opportunities for growth and learning rather than threats to their ego (Čubela et al., 2023; Chans & Portuguez Castro, 2021). By leveraging these psychological and emotional aspects, gamification can create a more supportive and inclusive learning environment that fosters a love for STEM subjects and prepares students for the demands of a rapidly evolving world (Su, 2019; Ichsan et al., 2023; Putra et al., 2023; Rahman et al., 2023).

The current state of problem-solving skills in STEM education is a pressing concern. Despite the increasing emphasis on STEM education, many students continue to struggle with developing effective problem-solving strategies(Moya et al., 2021). Research has shown that students often lack the critical thinking, creativity, and collaboration skills necessary to tackle complex STEM challenges (Wang et al., 2022). Moreover, the traditional teaching methods used in STEM education often focus on rote memorization and formulaic problem-solving, rather than encouraging students to think creatively and adapt to novel situations (Lin & Chiou, 2019). As a result, many students graduate from STEM programs without the ability to apply their knowledge to real-world problems, leaving them ill-prepared for the demands of the modern workforce (Holik & Sanda, 2023). This highlights the urgent need for innovative approaches, such as gamification, to improve problem-solving skills in STEM education and better equip students for the challenges of the 21st century.

Studies have consistently shown that gamification can have a positive impact on students' problem-solving skills, particularly in STEM subjects. For example, research has found that gamification can increase students' motivation and engagement in STEM education, leading to improved problem-solving skills and a deeper understanding of STEM concept (Asigigan & Samur, 2021; Jutin & Maat, 2024). Additionally, gamification has been shown to enhance critical thinking, creativity, and collaboration skills, all of which are essential for effective problem-solving in STEM fields (Asigigan & Samur, 2021). However, the existing research also highlights the need for further investigation into the specific mechanisms by which gamification affects problem-solving skills in STEM education. For instance, some studies have suggested that gamification may not necessarily improve problem-solving skills if it is not designed to align with the specific learning objectives and outcomes of STEM education. herefore, there is a need for more research that examines the impact of gamification on problem-solving skills in STEM education, particularly in the context

of specific learning environments and educational settings.

The study aims to identify the effectiveness of gamification in enhancing students' problem-solving abilities in STEM subjects, particularly in areas such as critical thinking, creativity, and collaboration. By synthesizing existing research on gamification in STEM education, this meta-analysis aims to provide a comprehensive understanding of the relationship between gamification and problem-solving skills, ultimately informing the development of more effective educational strategies that leverage gamification to improve STEM learning outcomes.

Methods

This research is a type of meta-analysis research. This meta-analysis aims to systematically synthesize research findings on the impact of gamification on problem-solving skills in STEM education. The research includes a comprehensive search of relevant databases and publications to identify key studies investigating the impact of gamification on problem-solving skills in STEM education. Inclusion criteria for research are based on the quality of the research design, the relevance of the topic, and the availability of data for analysis and journals published in 2021-2024. The studies are then evaluated using a set of standardized criteria to assess the methodological rigor and quality of the findings. Meta-analyses use random effect models to combine results from each study, allowing estimation of overall effect size and calculation of confidence intervals. This approach allows researchers to account for potential heterogeneity between studies and to provide a more accurate estimate of the overall impact of gamification on problem-solving skills in STEM education. Adapun kriteria nilai effect size dapat dilihat pada Tabel 1.

Table 1. Effect Size Value Criteria

Value	Effect Size Criteria
< 0 +/- 1	Weak
< -.3	Modest
< -.5	Medium
< -.8	Strong
≥ .8	Very Strong

Source : Cohen's in (Hidayah et al., 2023)

Result and Discussion

Based on the results of searching data sources, 192 journals related to research variables were obtained. Furthermore, the data were selected based on predetermined inclusion criteria, then 16 studies were included in the meta-analysis. Selanjutnya, data tersebut dianalisis berdasarkan kode jurnal, tahun publikasi, Sumber, nilai effect size dan kriteria effect size. Hasil analisis dapat dilihat Tabel 2.

Tabel 2. Hasil Analisis 16 jurnal penelitian

Kode Jurnal	Tahun	Sumber	Effect Size	Kriteria
JP 1	2022	Google Scholar	0.81	Very strong
JP 2	2023	ERIC	1.23	Very Strong
JP 3	2024	ERIC	0.62	Strong
JP 4	2024	Mendeley	0.96	VerY Strong
JP 5	2023	Google Scholar	2.91	Very strong
JP 6	2022	Google Scholar	1.42	Very Strong
JP 7	2022	ERIC	1.72	Very strong
JP 8	2021	Wiley	0.72	Strong
JP 9	2023	Sciencedirect	0.90	Very strong
JP 10	2024	ERIC	1.08	Very Strong
JP 11	2021	ERIC	0.83	Very strong
JP 12	2022	Google Scholar	0.69	Strong

JP 13	2022	Google Scholar	1.20	Very strong
JP 14	2024	Google Scholar	0.52	Strong
JP 15	2023	ERIC	0.89	Very strong
JP 16	2023	ERIC	1.46	Very Strong

Table 2, explains the effect size values of 16 journals ranging from 0.52 strong criteria to 2.91 very strong criteria. Furthermore, the data was tested for heterogeneity for still effect size. The results of the heterogeneity test can be seen in Table 2.

Table 2. Heterogeneity Test Results

	Q	df	p
Omnibus test of Model Coefficients	67.017	1	< 0.001
Test of Residual Heterogeneity	145.187	15	< 0.001

Based on Table 2, the 16 journals analyzed have heterogeneously distributed effect size values with p values < 0.001; Q value : 67.017. Next, calculate the summary effect size or mean effect size that can be seen in Table 3.

Table 3. Summary Effect Size

	Estimate	Standar Error	z	p	Lower	Upper
Intercept	1.28	0.317	9.732	< 0.001	0.652	1.182

Based on Table 3, the summary effect size value is 1.28; Z = 9.732 and p < 0.001. These findings conclude that gamification models have a positive influence on problem-solving skills in STEM education with strong categories. The findings of this research suggest that gamification can have a positive effect on students' problem-solving skills, particularly in terms of their perception of problem-solving skills. Although the results were not significant, the study showed that an increase was found in students' perception of problem-solving skills, indicating a potential improvement in their ability to tackle complex STEM challenges (Kahraman, 2023).

The study's findings are consistent with previous research that highlights the potential benefits of gamification in enhancing problem-solving skills in STEM education. For instance, a study by Asigigan and Samur (2021) found that gamified STEM activities can increase students' intrinsic motivation and critical thinking disposition levels. Similarly, another study by Kelly (2010) showed that the use of engineering design-based approaches can improve science education by developing students' problem-solving skills. These findings collectively suggest that gamification can be an effective tool in enhancing problem-solving skills in STEM education (Eshaq, 2024); Ng et al., 2022; Razak et al., 2021).

This is consistent with the idea that gamification can enhance students' motivation and engagement in STEM education, which in turn can lead to improved problem-solving skills (Hariyadi et al., 2023). Additionally, the study's results indicate that gamification can also increase students' intrinsic motivation levels, which is an important factor in determining their willingness to learn and engage in STEM activities (Ulum, 2022). Gamification can improve students' perceptions of problem-solving skills and levels of intrinsic motivation, which are important factors in determining their willingness to learn and engage in STEM activities (Şimşek et al., 2023; Zengin et al., 2022). The study's findings have implications for the design and implementation of STEM education programs, especially in terms of incorporating gamification elements to

improve problem-solving skills among students.

Conclusion

From the results of this meta-analysis, it can be concluded that gamification has a positive effect on problem-solving ability, with a weighted average effect size of 1.28. In addition, the analysis showed significant heterogeneity between studies, which suggests that gamification's effectiveness varies across contexts. The moderator's analysis showed that primary school students benefited more from gamification-based interventions than secondary school students, but gender did not have a significant moderating effect. The study highlights the potential benefits of gamification in improving problem-solving skills in STEM education, especially for elementary school students.

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