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GAMIFICATION IN THE STEM DOMAIN SUBJECT: THE PROSPECTIVE METHOD TO STRENGTHEN TEACHING AND LEARNING

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ABSTRACT

Several meta-analysis studies related to game-based learning or Gamification have been carried out by various researchers. However, there is still a scarcity of studies specifically elucidating the extent of Gamification's impact on STEM domain subjects. Therefore, this research aims to summarize various research results related to the influence of game-based learning in improving student learning outcomes in STEM domain subjects. This research was a meta-analysis using the standardized group contrast design with a random model. Research data were from articles published in Scopus-indexed journals or proceedings. The inclusion criteria in this research were articles published between 2014 – 2023 in English, quantitative type data with a contrast group design containing control and experimental groups, complete data (n, mean, SD), and research focused on STEM domain subjects. The data collection process used the PRISMA method. To ensure data quality, researchers conducted publication bias analysis using the fail-safe N method. The moderator variables were continent, stem domain, era, developing competency, game type, and education level. The results find that Gamification has a positive impact on student learning outcomes, as indicated by an effect size value of 0.5492 [0.3943; 0.7041] with a confidence interval of 95%. Gamification does not provide a significant positive difference in the moderator variables continent, era, developing competence, and game type. For STEM domain subjects, Gamification is highly recommended to be applied. For the educational level, Gamification is most recommended to be implemented in elementary school.

Keywords: gamification; meta-analysis; subject of learning; teaching and learning; STEM domain

INTRODUCTION

STEM, which stands for Science, Technology, Engineering, and Mathematics, is a learning approach widely used in the world (Arlinwibowo et al., 2020c; Arlinwibowo et al., 2021b; Arlinwibowo et al., 2023). It was begun by America to increase the global competitiveness of its society, and STEM scientific domains must be emphasized in its education system (Chesky & Wolfmeyer, 2015; Bicer et al., 2017). Then, various countries also emphasize strengthening mastery of STEM scientific domains through educational fields (Khaeroningtyas et al., 2016; Ong et al., 2016; Wan Husin et al., 2016; Çevik, 2018; Wisudawati, 2018). In light of the technological advancements in the 21st century, it is not an overstatement to regard STEM as a profoundly important discipline that significantly influences competitiveness.

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However, students face various challenges in mastering the STEM (Science, Technology, Engineering, and Mathematics) domain (Retnawati et al., 2017). Mathematics is considered the most challenging domain for students due to its abstract nature, where only some students possess strong abstraction skills (Arlinwibowo & Rernawati, 2015; Marsigit et al., 2020). Additionally, the science domain presents challenges, as some students perceive it as overly theoretical and difficult to comprehend (Retnawati et al., 2017). Lastly, engineering and technology domains are based on complex concepts, requiring students to master high-level thinking skills for effective learning (Arlinwibowo et al., 2020b; Arlinwibowo et al., 2021a). Despite these challenges, many students are capable of mastering STEM subjects. One of the key determinants is the high motivation of these students to learn the domain. Empirically, games have been proven to enhance students' learning motivation in STEM subjects (Ibrahim et al., 2020; Janković & Lambić, 2022).

Game is considered one of the platforms that can enhance an individual's cognition (Piaget, 2013), increase learning appeal (Öztürk & Korkmaz, 2020), make students enjoy learning (Papastergiou, 2009), and provide opportunities to incorporate various real-world contexts (Chu & Chang, 2014). However, the implementation of game-based learning still faces various challenges. The most common constraints include infrastructure issues, funding, school policies (Kaimara et al., 2021), the complexity of instructional design, teachers' ability to organize learning (Manesis, 2020), and students' gaming skills (Stankova et al., 2021). Therefore, it becomes interesting to question whether game-based learning can improve students' learning outcomes. In theory, games can enhance the appeal and motivation of STEM subjects (Papastergiou, 2009; Piaget, 2013; Chu & Chang, 2014). However, many challenges must be faced (Manesis, 2020; Kaimara et al., 2021; Stankova et al., 2021). The negative effects of Gamification found in previous research are disparity in facilities, too much time allocation, too many students in class, and the difficulty of integrating games into learning according to the curriculum (Lee et al., 2022), such as the tight ranking system (win/lose) in games (Toda et al., 2018).

Some studies demonstrate that game-based learning has a beneficial influence (Janković & Lambić, 2022; Legaki et al., 2020), while others show that it has a detrimental impact when compared to traditional techniques (Deng et al., 2020; Fitriyana et al., 2021; Legaki et al., 2021). These opposing findings are worth summarizing. The synthesis of diverse study findings will offer readers a general overview to use as a foundation when considering game-based learning implementation. Meta-analysis is one of the quantitative tools that can help researchers summarize data from prior studies (Utami et al., 2022; Hernanda et al., 2023). As a result, the purpose of this study is to summarize diverse research findings concerning the impact of game-based learning on improving student learning outcomes in STEM topics.

Until now, several meta-analysis studies related to game-based learning or Gamification have been conducted by various researchers. The common findings suggest that gamification or game-based learning improves learning outcomes (Kim & Castelli, 2021; Mazeas et al., 2022). Researchers argue that game-based learning makes students more enthusiastic and happier (Mazeas et al., 2022) and helps them understand contexts (Kim & Castelli, 2021), thereby enhancing learning motivation (Mamekova et al., 2021) and improving learning outcomes (Fadhli et al., 2020). A meta-analysis study specifically focuses on the relationship between gamification and STEM learning but only concentrates on virtual games with data from 2010 to 2020 (Wang et al., 2022). This recent meta-analysis study aims to analyze the impact of games (both virtual and non-virtual) on learning outcomes (attitudes, knowledge, and skills) with the most recent data from the last ten years to provide a more realistic picture of the situation before and after COVID-19. The research is also enriched with several moderator variables that can describe the dataset in more detail, allowing readers to understand the impact of game-based learning.

METHODS

This was a meta-analysis study with the goal of determining the possible enhancement of learning quality by Gamification in STEM (Science, Technology, Engineering, and Mathematics) subjects. Meta-analysis is a systematic study of quantitative data that allows researchers to summarize the findings of prior studies (Retnawati et al., 2018). It will produce a numerical conclusion in the form of an effect index that represents findings from a collection of studies with similar themes.

This research was carried out in several steps, namely: 1) Determine the research theme; 2) Determine the data population and research variables; 3) Determine a complete data search mechanism with inclusion and exclusion criteria; 4) Determine data networking procedures based on the PRISMA model; 5) Determine the moderator variable to be analyzed; 6) Carry out the analysis process; 7) Report findings.

This study used research data published online. The data search strategy involved using the sciencedirect.com website and the Publish or Perish application on Scopus-indexed data. This approach aimed to include high-quality articles that meet the standards of Scopus-indexed journals or proceedings. The strategy was based on the assumption that the review processes in these journals adhere to strict protocols, reducing the potential for obtaining articles with research quality below standard. In the search process, the researcher employed a combination of keywords representing the research theme, including "gamification," "STEM Education," "game," "achievement," and "learning outcome." To gather more comprehensive articles, Boolean operators (AND, OR) were used.

The researchers followed inclusion and exclusion criteria during the data screening phase. Articles that met all of the inclusion criteria were chosen. There were also exclusion criteria that were the inverse of the inclusion criteria. If an article fails to match any of the inclusion criteria, it is removed from the dataset that can be analyzed. Table 1 displays the study's inclusion and exclusion criteria.

Table 1. Inclusion and Exclusion Criteria

Aspect	Inclusion Criteria	Exclusion Criteria
Time	2014 - 2023	Else
Language	English	Else
Data Type	Quantitative	Qualitative
Research Design	Group Contrast	Else
Data Set	Control and experiment	Does not load either or both
Data Component	Sample Size, Mean, and Standard Deviation	Does not load one, two, or all three
Analysis Data	Quantitative	Qualitative
Theme	Gamification to improve the quality of learning	Else
Focus	STEM Domain Subjects	Else
Journal or Proceeding Index	Scopus	Else

For greater clarity, the data collection process is shown in Figure 1. 20 articles met the inclusion requirements, making them eligible to enter the analysis stage. Figure 1 explains the flow of the literature filtering process to produce literature that contains data according to analysis needs. The initial search found 234 articles. Then, through a strict screening process based on the specified inclusion criteria, 20 articles that contained complete data and appropriate themes were found.

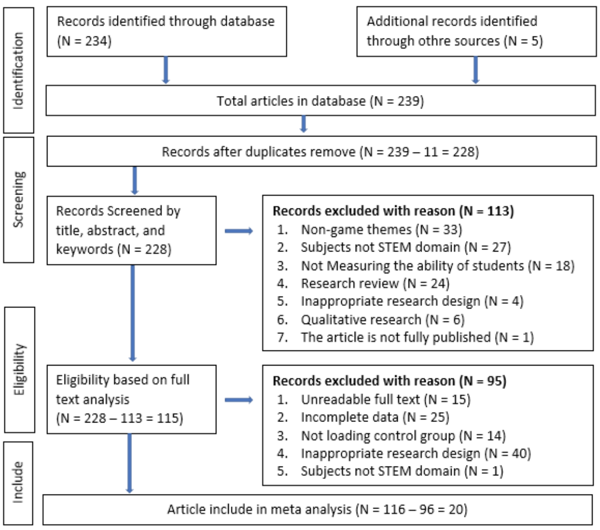

Figure 1. PRISMA-based Database Selection Process

From the 20 articles obtained in the PRISMA selection process, some articles provided diverse information, allowing for the extraction of more than one set of data for analysis. For example, the article by Chen et al. (2020) contained varied data, all relevant to the research theme; thus, one article yielded information on emotions and achievement in game-based learning. Additionally, the samples were divided into three categories: high achievers, middle achievers, and low achievers. Consequently, six studies were derived from this single article. Mapping the results of the 20 articles yielded 60 data available for meta-analysis to conclude the potential of Gamification in enhancing the quality of the learning process in STEM subjects. Moderator variables were selected to provide a deeper description of the meta-analysis findings. The total effect size of the meta-analysis indicated the general potential of Gamification to improve learning performance in STEM subjects, and the analysis of moderator variables produced more specific findings to highlight other influencing factors. The moderator variables in this study included continent, STEM domain, era, evolving competencies, game type, and educational level. The analysis of moderator variables utilized ANOVA-like models to indicate the position of each moderator variable concerning the effect size. The technique for inferring interactions in the moderating variable was to look at the p-value. If the p-value <0.05, then the interaction in the moderating variable has a significant difference.

Table 2. Moderator Variables

Moderator Variable	Identified Categories	freq	%
Continent	Euro	18	30.0%
	Asia	37	61.7%
	America	5	8.3%
STEM domain	Math	27	45.0%
	Science	18	30.0%
	Engineering	15	25.0%
Era	Pre-Covid (published before 2020)	38	63.3%
	Post-Covid (2020 publications and after)	22	36.7%
Developing Competence	Affective	13	21.7%
	Knowledge	20	33.3%
	Skill	23	38.3%
Type game	Virtual	34	56.7%
	Non-Virtual	26	43.3%
Education level	University	21	35.0%
	Senior High School	7	11.7%
	Junior High School	20	33.3%
	Elementary	8	13.3%
	Preschool	4	6.7%

This study utilized highly varied data sources. This was demonstrated by the researcher collecting research results from all continents (Asia, Europe, and America), educational levels (from preschool to high school and beyond), game types (virtual and non-virtual), and evolving competencies (affective, cognitive, and skills). Thus, this study used a random-effects model, assuming that population variance contributes to variance in the effect size due to the different populations (Borenstein, 2009; Retnawati et al., 2018). The assumption of population variance was then clarified with a test of data heterogeneity (Borenstein, 2009). The heterogeneity test used the Q, Ʈ2, and I2 methods. An effect size between studies was considered heterogeneous when the Q p-value was below 0.05 (for a 95% confidence interval), Ʈ2 > 0 (Retnawati et al., 2018), and I2 values indicating low (0-25%), moderate (25%-75%), and substantial heterogeneity (75%-100%) (Higgins, 2003).

The meta-analysis in this study used a standardized group contrast design. Standardization was performed because the scale of values among data was highly diverse, requiring standardization to produce proportional aggregates among studies (Arlinwibowo et al., 2022). To determine the total effect size (d), the first step was to calculate it using the formula as follows (Retnawati et al., 2018).

$$d = \frac{\bar{X}_1 - \bar{X}_2}{S_{within}}, \qquad S_{within} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{(n_1 - 1)(n_2 - 1)}}$$

Then, to determine the standard error of d (SE_d), the formula was:

$$SE_d = \sqrt{V_d}, \qquad with\ V_d = \frac{n_1 + n_2}{n_1 n_2} + \frac{d^2}{2(n_1 + n_2)}$$

To minimize bias, the effect size and standard error were then converted using the formula proposed by (Hedges, 1981):

$$g = J \times d, \qquad J = 1 - \frac{3}{4df - 1}, \qquad df = degree\ of\ freedom\ (n_1 + n_2 - 2)$$

$$SE_g = \sqrt{V_g}, \qquad with\ V_g = J \times V_d$$

The process of calculating effect size and standard error used the R application with the meta and metafor packages. The results of effect size and standard error served as the basis for visual representations in the form of forest plots and funnel plots. The effect size results could be classified into five categories: no effect, low effect, moderate effect, high effect, and very high effect (Sullivan & Feinn, 2012). The classification table for effect size values is presented in Table 3.

Table 3. Effect Size Categories Results of Meta-Analysis of Contrast Group Model

Effect Size	Category
0 – 0.19	No Effect
0.20 – 0.49	Small
0.50 – 0.79	Medium
0.80 – 1.29	Large
> 1.30	Very Large

To ensure the quality of the gathered data, this study needed to demonstrate freedom from publication bias. Techniques for demonstrating bias intervention included funnel plots, Egger's test, and fail-safe N. A meta-analysis study is considered free from publication bias when the fail-safe N value > 5K + 10, where K is the number of studies (Mullen et al., 2001)

RESULTS AND DISCUSSION

This research analyzed 60 studies taken from 20 research results. This research was conducted in various countries and continents, involving preschool, elementary and high school, and university students. Based on those data, this research analyzed the data that was assumed to be heterogeneous to conclude the potential for using games to improve the quality of learning in STEM domain subjects. The following is an explanation of the Meta-analysis results: proving the heterogeneity assumption, exploring the publication of data bias, inferring effect sizes, and analyzing moderator variables by utilizing the R application with the Meta and metafor packages.

Three methods, namely $Ʈ^2$, I^2, and Q, were used to prove the heterogeneity. These three methods were used to guarantee the accuracy of judgment to prove heterogeneity. The analysis results show that Ʈ2 = 0.2979 [0.2147; 0.5732] > 0 (Retnawati et al., 2018). Thus, based on the $Ʈ^2$ value, it can be concluded that the data in this study are heterogeneous. Analysis results I^2 = 77.9% [71.9%; 82.7%] fall into the substantially heterogeneous data category, so it can be concluded that based on I^2, the data in this study are heterogeneous (Higgins, 2003). The Q test results show a p-value < 0.0001, which is below 0.05 (for a confidence interval of 95%), so according to the Q test, it can be concluded that the data in this study are heterogeneous (Retnawati et al., 2018). Thus, selecting a random model in Meta-analysis is appropriate regarding data characteristics and statistics.

Identification of publication bias is proven using the file-safe N method with the criteria that data is said to be free from publication bias when N > 5K + 10 (N is the fail-safe value of N and K is the number of studies). The analysis output shows Fail-safe N: 5332 for a confidence level of 95%. Thus, N = 5332 > 5 × 60 +10 = 310. Based on these calculations, it is proven that the data is free from publication bias (Mullen et al., 2001) so that the meta-analysis results can be trusted.

After the random model selection is confirmed to be correct and devoid of publication bias, the meta-analysis process can be repeated to ascertain the conclusion of the differences between the two groups. The effect size represents the difference between the two groups. The study findings suggest that the random effect size model has an effect size of 0.5492 [0.3943; 0.7041] and a p-value of 0.0001 with a confidence level of 95% (Hedges, 1981).

The p-value is 0.0001 0.05 based on this result, indicating that there is a significant difference between the two groups being compared. The groups compared in this study are students taught using non-game approaches and students taught using game-based learning. The interpretable outcomes of the second analysis are 0.5492 [0.3943; 0.7041]. According to the results of this examination, the total effect size is 0.5492. A range of total effect size values is discovered between 0.3943 and 0.7041 with a confidence interval of 95%. A positive result implies that the game-based learning group outperforms the non-game-based learning group in terms of learning outcomes. The effect size indicates that the strength of the differences between the two groups is moderate (Sullivan & Feinn, 2012). The results of this meta-analysis are consistent with earlier research by Kim and Castelli (2021), Mazeas et al. (2022), and Wang et al. (2022).

Forest plot visualization can show comprehensive analysis results. The forest plot of the analysis output using the R application contains a summary of the raw data, the mean effect size for each study, the standard error for each study, the total effect size, and the total standard error. The forest plot can be seen in Figure 2 as follows.

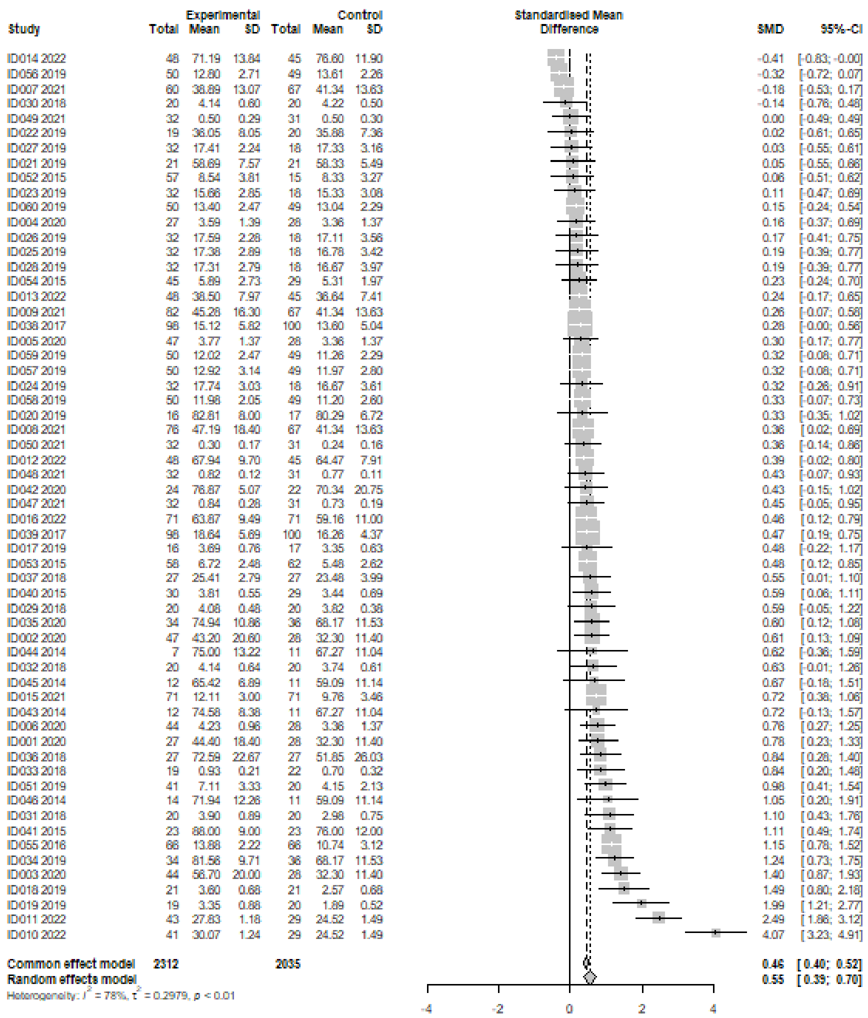

Figure 2. Forest Plot

The general description of the impact of game-based learning on improving the quality of learning shows a positive effect with medium strength. Analysis of moderator variables can provide a more in-depth portrayal of various other factors that have an influence.

In this research, the moderator variables analyzed are continent, STEM domain, era, competencies developed, game type, and education level. The results of the moderator variable analysis are summarized in the forest plot in Figure 3.

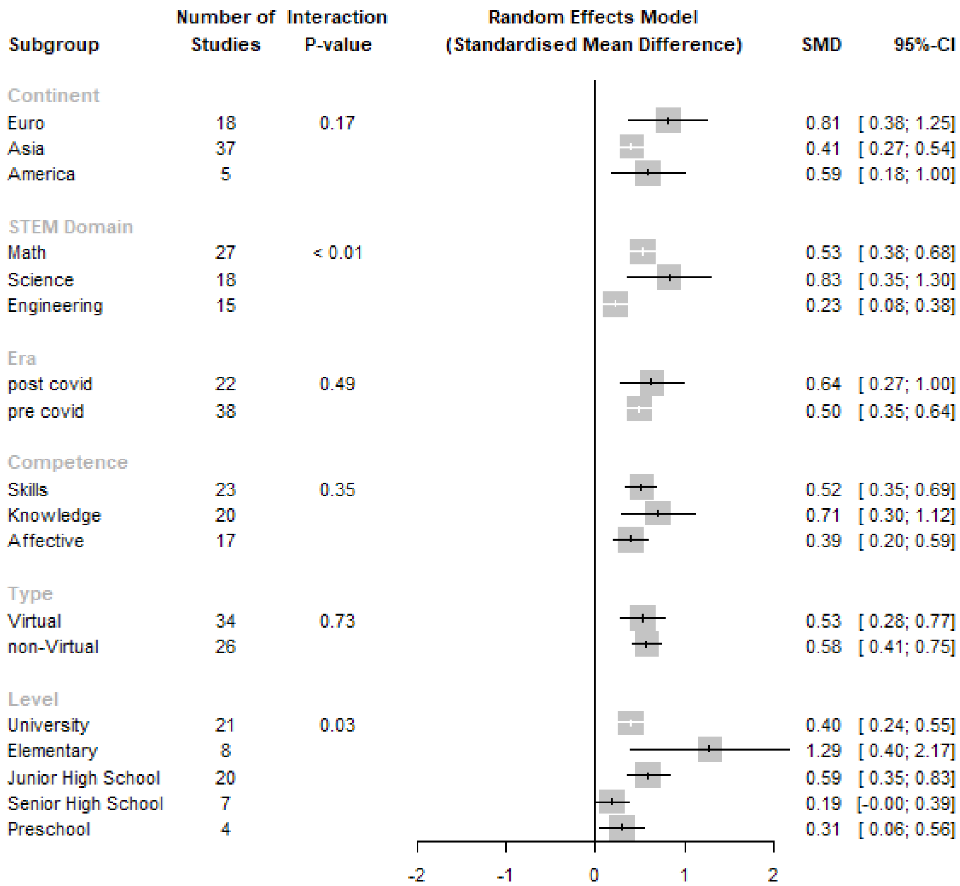

Figure 3. Interaction and Forest Plot of Moderator Variables

Based on the analysis output in Figure 3,Based on the analysis output in Figure 3, we can interpret the influence of various moderator variables that have been selected in this research. The first moderator variable is the continent where the research is conducted. Many studies suggest that there are differences in the character of education in each location or country (Arlinwibowo et al., 2020c) or continent (Uysal, 2009; Kartianom & Ndayizeye, 2017). Thus, it becomes essential to show the impact of independent variables based on research location. When the p-value is less than 0.05 (a confidence interval of 95%), each continent has a different effect of game-based learning on increasing the quality of learning. The interaction P-value is 0.17, indicating that there are no significant differences between the three continents: Europe, Asia, and America. As a result, the utilization of game-based learning has the same or a similar beneficial influence on the quality of learning in STEM domain subjects across the three continents. The positive impacts of game-based learning are unaffected by the differences in characteristics between countries grouped by continent.

The second moderator variable is STEM domain subjects. Identification based on this moderating variable is intended to explore the effects of Gamification for each STEM domain subject. Each subject has its character (Kelley & Knowles, 2016; Arlinwibowo et al., 2020c; Gale et al., 2020). Thus, it is possible for a strategy to produce different results for each subject. The p-value, with a confidence interval of 95%, indicates that there is a significant difference in the impact of Gamification based on STEM domain subjects. As a result, it is possible to conclude that Gamification improves all aspects of the learning process in STEM domain subjects. These findings are consistent with previous research findings from a meta-analysis (Sailer & Homner, 2020; Wang et al., 2022; Arztmann et al., 2023).

The influence on science subjects is the highest, followed by mathematics, and the smallest influence on engineering subjects. Based on these findings, it is possible for recommendations to develop various products in the form of models, methods, and teaching aids to support the implementation of Gamification for science and mathematics learning.

There are various opportunities to improve and strengthen the quality of mathematics and science education through Gamification. The third moderator variable is the period when the research is carried out. The period is divided into two, namely pre-covid and post-covid. This distribution is carried out based on extraordinary dynamics that occurred during the COVID-19 pandemic (Bozkurt et al., 2022). The world of education has been impacted so tremendously that there have been various massive transformations in the education system in all countries (Arlinwibowo et al., 2020d). Thus, it is important to know whether there are differences in the impact of Gamification in the two eras. The P-value of the interaction shows 0.49 > 0.05, which indicates that there is no significant difference between the two periods. It means that Gamification can improve the quality of learning in STEM domain subjects before and after COVID-19. These findings can be interpreted as a judgment that Gamification suits diverse learning conditions. Implementing game-based learning does not need to worry about its relevance at any time.

The fourth moderator variable is developed competence. Education has a mission to develop student competencies comprehensively (Zurqoni et al., 2018; Arlinwibowo et al., 2021b, 2021a). An in-depth study of these moderator variables is crucial to see the suitability of game-based learning for the competency targets being developed. Competencies are divided into three categories: affective, knowledge, and skills (Arlinwibowo et al., 2020a). The interaction p-value shows 0.35 > 0.05, indicating no significant differences in the three types of competencies. It means that Gamification has an equally good influence on the development of students' affection, knowledge, and skills. Thus, there is no need to hesitate in choosing the type of competency to be developed when implementing game-based learning.

The fifth moderator variable is the type of game, which is classified into virtual (digital) and non-virtual (physical). Not all locations and ages are suited to virtual gaming (Retnawati et al., 2017). Technology can improve the learning process (Marsigit et al., 2020) but can also cause difficulties. Traditional games are more likely to be involved in the learning process in areas with minimal facilities. Thus, the influence of both types of games needs to be explored. The P-value of the interaction shows 0.73 > 0.05, indicating no significant difference between the two types of games. It means that both types of games have the same effect in improving the quality of student learning in STEM domain subjects. Teachers can adapt game-based learning designs according to their respective conditions with virtual and traditional games.

The sixth or final moderator variable is the level of students taught with game-based learning. Levels are divided into 5; preschool (< 7 y.o.), elementary (grades 1-6), junior high school (grades 7-9), senior high school (grades 10-12), and university (> 18 y.o.). Investigating the suitability of game-based learning at a school level is very important because students have different characteristics at each level (Kraevskii, 2006). These character differences influence many elements, including learning style and orientation. The p-value interaction value shows a very small value, namely < 0.03 < 0.05. With a confidence interval of 95%, the p-value shows that there is a significant difference in the impact of Gamification based on school level. It means that Gamification has a good impact at all levels, but application at the elementary level has the greatest impact. Uniquely, Gamification does not have a very significant impact at the senior high school level. This is because elementary school students are very interested in games (Lucas, 2017). In this way, integrating games into the learning process makes them like learning more (Nand et al., 2019) and even makes learning that was previously considered difficult easier (Udjaja et al., 2018). Based on these findings, Gamification is highly recommended to be applied to learning STEM domain subjects at elementary school.

CONCLUSION

In analytical research, the use of a random model has demonstrated to be adequate in terms of data features and statistics τ^2, I^2, and Q. Based on the results of the Fail-Safe N analysis, the data obtained has been shown to be free of biased publications. As a result, the analysis methodologies selected are appropriate, and the results may be trusted because they have been demonstrated to be free of biased publishing. Gamification has beneficial effects on student learning outcomes, as evidenced by an effect size value of 0.5492 [0.3943; 0.7041] with a confidence interval of 95%. In the moderator variables of continent, era, improving competency, and game type, gamification does not give a substantial positive impact. It means that game-based learning should be used regardless of location or competencies being cultivated. It can include any form of game (virtual or non-virtual) and is applicable both before and after the pandemic. Gamification is mainly recommended for STEM domain subjects to be applied to. It is most commonly used in elementary schools for educational purposes.

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