Journal of Mathematics Education
Website: http://usnsj.id/index.php/JME
Email: pengelolajme@gmail.com
p-ISSN 2528-2468; e–ISSN 2528-2026

DOI: https://doi.org/10.31327/jme.v11i2.2858

Effect of STEM Context-Based Challenge-Based Learning with Gamification on Students' Critical Thinking and Mathematical Resilience

Sigit Dwi Kurniawan*[1], Ariyadi Wijaya[2]
[1,2] Universitas Negeri Yogyakarta

Article Info

Article history:

Received Jul 25, 2026
Revised Aug 02, 2026
Accepted Aug 18, 2026

Keywords:

Challenge Based Learning
STEM Context
Gamification
Critical Thinking Skills
Mathematical Resilience

ABSTRACT

This study aims to: (1) describe the effect of the STEM Context-based Challenge Based Learning model with gamification on students' critical thinking skills and mathematical resilience; (2) describe which is superior between the STEM Context-based Challenge Based Learning model with gamification and the Problem Based Learning model on students' critical thinking skills; (3) describe which is superior between the STEM Context-based Challenge Based Learning model with gamification and the Problem Based Learning model on students' mathematical resilience. This study is a quasi-experimental study with a pretest-posttest non-equivalent control group design. The population in this study were all seventh-grade students of SMP Negeri 1 Tegalrejo in the even semester of the 2025/2026 academic year. The sample used in this study were 30 students from classes VII-A and VII-F. Class VII-A served as the experimental class, treated with the STEM Context-based Challenge Based Learning model with gamification, and class VII-F served as the control class, treated with the Problem Based Learning model. The data collection method used was a critical thinking ability test instrument and a non-test questionnaire on students' mathematical resilience. The instruments in this study were validated using content validity with expert judgment, empirical validity tested using construct validity, and reliability estimated using the Cronbach's Alpha formula. Inferential statistical data analysis used the Hotelling's T2 test, the Independent Sample t-test, and Effect Size. The results showed that the Challenge Based Learning model based on STEM Context with gamification had an effect on students' critical thinking skills and mathematical resilience. The Challenge Based Learning model based on STEM Context with gamification was superior to the Problem Based Learning model in terms of students' critical thinking skills and mathematical resilience.

Corresponding Author:

Sigit Dwi Kurniawan,
Departement of Mathematics Education,
Universitas Negeri Yogyakarta, Indonesia
Email: sigitdwi.2024@student.uny.ac.id

How to Cite:

Kurniawan, S.D., & Wijaya, A. (2026). Effect of STEM Context-Based Challenge-Based Learning With Gamification on Students' Critical Thinking And Mathematical Resilience. *JME:Journal of Mathematics Education*, *11*(2), 457- 468.

1. INTRODUCTION

21st-century education faces significant challenges in preparing learners to adapt to advancements in science and technology, as well as increasingly complex social changes. The Fourth Industrial Revolution (Industry 4.0) and Society 5.0 demand that learners possess higher-order thinking skills, problem-solving abilities, creativity, collaborative skills, and resilience in the face of various challenges. This situation highlights the need for instructional innovations that not only develop cognitive abilities but also build students' psychological readiness to cope with learning difficulties.

Critical thinking is a key 21st-century competency. It encompasses the ability to interpret information, analyze and evaluate evidence, draw inferences, provide logical explanations, and exercise self-regulation during decision-making processes (Facione, 2011). In mathematics education, this skill is crucial, as students are required to analyze situations, connect various concepts, and solve complex problems. Beyond cognitive aspects, success in learning mathematics is also influenced by a student's ability to persevere when facing difficulties. "Mathematical resilience" refers to an individual's capacity to remain motivated, view errors as part of the learning process, and persist in finding solution strategies when encountering challenging mathematical problems (Masten, 2001; Reivich & Shatté, 2002; Yeager & Dweck, 2012). Therefore, mathematics instruction needs to be designed to foster critical thinking skills while simultaneously strengthening mathematical resilience.

One approach considered capable of meeting these needs is Challenge-Based Learning (CBL). This approach positions students as problem solvers who address real-world challenges relevant to their daily lives, thereby fostering processes of investigation, collaboration, reflection, and decision-making (Johnson et al., 2009; Nichols et al., 2016). Research by Krajcik et al. (2014) demonstrated that challenge-based learning (CBL) enhances conceptual understanding because learners acquire knowledge through authentic experiences and the application of knowledge in real-world contexts.

The effectiveness of CBL can be bolstered by integrating the Science, Technology, Engineering, and Mathematics (STEM) approach. STEM is an interdisciplinary learning approach that connects concepts from science, technology, engineering, and mathematics to solve authentic problems. STEM integration encourages learners to think systematically, develop creativity, and apply mathematical concepts within real-life contexts (Beers, 2011; Fisher & Frey, 2017). The alignment between the characteristics of CBL and the STEM approach allows them to complement each other in creating a learning experience centered on problem-solving, collaboration, and innovation.

Implementing STEM-based CBL also requires technological support capable of boosting learner motivation and engagement throughout the learning process. One widely developed strategy is gamification—the application of game elements such as points, levels, challenges, rewards, and feedback within the learning environment to enhance learner motivation, participation, and persistence (Baldrich et al., 2023; Febriansah et al., 2024). Platforms like Nearpod offer various interactive features—including quizzes, real-time collaboration, simulations, and immediate feedback—that facilitate the implementation of gamification in learning. Previous research indicates that gamification can increase learning engagement while fostering a more meaningful learning experience (Bailey et al., 2021; Khaldi et al., 2023; Praptomo et al., 2024).

However, previous research generally still examines these components separately. Hidayat et al. (2022) reported that CBL is effective in improving critical thinking skills, but has not integrated STEM contexts or digital media. Sari et al. (2020) shows that CBL is able to increase mathematical resilience, but has not tested its effect on critical thinking skills simultaneously. Raivo's (2022) research has integrated STEM nuances into CBL through the use of learning media, while Bailey et al. (2021) proves that Nearpod increases student engagement. However, empirical evidence regarding the effectiveness of learning that integratedly combines CBL, STEM contexts, and gamification on junior high school students' critical thinking skills and mathematical resilience is still limited.

Based on this gap, this research offers novelty in the form of integrating Challenge-Based Learning, STEM contexts, and Nearpod-based gamification in one comprehensive learning design. In contrast to previous research which only focused on one or two components, this research analyzes the effect of integrating these three components simultaneously on two important 21st century competencies, namely critical thinking skills and mathematical resilience. The results of this research are expected to provide an empirical contribution to the development of technology-based mathematics learning which not only improves high-level thinking abilities, but also strengthens students' resilience in facing the challenges of learning mathematics.

2. METHOD

This study employs a quasi-experimental research method with a non-equivalent control group pretest–posttest design. This design was selected because individual randomization of subjects was not feasible; consequently, existing classes were utilized as the experimental and control groups. The research design is presented as follows.

Table 1. Research Design.

Group	Pretest	Treatment	Posttest
Eksperiment	O_1	X_1	O_2
Control	O_3	X_2	O_4

Note:
X_1 = STEM-context-based Challenge-Based Learning assisted by gamification.
X_2 = The instruction previously implemented at the school (problem-based learning)

The study was conducted at a school in Magelang Regency during the odd semester of the 2025/2026 academic year. The research population consisted of all Grade VII students, comprising two classes with a total of 60 students. The sample was selected using a cluster random sampling technique, wherein all Grade VII classes were randomized to determine the experimental and control groups. The randomization process designated Class VII A (n = 30) as the experimental group and Class VII G (n = 30) as the control group.

The independent variable in this study was the implementation of STEM Context-Based Challenge-Based Learning supported by gamification via Nearpod, while the dependent variables were students' mathematical critical thinking skills and mathematical resilience. To minimize the influence of extraneous variables, the teacher, learning materials, time allocation, and evaluation instruments were standardized across both groups.

The treatment was administered over three sessions covering the topic of lines and angles. In the experimental group, instruction followed the Challenge-Based Learning framework, integrated with a STEM context and supported by gamification through Nearpod. Students were presented with authentic problems, designed alternative solutions, engaged in exploration and group discussions, presented their findings, and received feedback via various interactive Nearpod features such as quizzes, challenges, and point systems. Meanwhile, the control group received instruction using the conventional teaching model standard to the school.

Data collection involved both test and non-test instruments. The test instruments consisted of pre-tests and post-tests in the form of essay questions designed to measure mathematical critical thinking skills based on the indicators of interpretation, analysis, evaluation, inference, and explanation (Facione, 2011). The non-test instrument was a mathematical resilience questionnaire comprising 28 statements on a five-point Likert scale, used to measure students' resilience in the context of mathematics learning.

Prior to use, all instruments underwent validity and reliability testing. Content validity was assessed by three experts specializing in mathematics education and learning evaluation. The assessment results indicated that all instrument items fell into the valid category and were suitable for use following revisions based on validator feedback. Subsequently, the construct validity of the mathematical resilience questionnaire was analyzed using Exploratory Factor Analysis (EFA). The analysis results showed that the data met the requirements for factor analysis (KMO = 0.83), with all indicators exhibiting factor loading values above 0.50, thereby confirming construct validity. Instrument reliability was calculated using Cronbach's Alpha coefficient. The analysis revealed that the critical thinking ability instrument had a reliability coefficient of $\alpha = 0.8601$, while the mathematical resilience questionnaire had a reliability coefficient of $\alpha = 0.8496$, indicating good reliability for both instruments.

Data were analyzed using descriptive and inferential statistics. Descriptive statistics were employed to describe the mean, standard deviation, minimum score, and maximum score for each variable. Prior to hypothesis testing, prerequisite tests were conducted, including the Shapiro–Wilk test for univariate normality, the Henze–Zirkler test for multivariate normality, Levene's test for homogeneity of variance, and Box's M test for homogeneity of covariance matrices. Hypothesis testing subsequently involved: 1) a test for the difference in initial condition means, 2) a test for the difference in means after treatment, 3) an independent t-test, and 4) effect size calculation.

Effect size was also calculated to determine the magnitude of the difference between the experimental and control groups. Cohen’s d was used as a standardized measure of effect size, calculated by dividing the difference between the mean scores of the two groups by the pooled standard deviation (Cohen, 1988). The pooled standard deviation was calculated based on the sample size and standard deviation of each group. Cohen’s d values of 0.20, 0.50, and 0.80 were interpreted as small, medium, and large effects, respectively. Thus, Cohen’s d was used to complement the hypothesis testing results by indicating the practical magnitude of the effect of STEM Context-Based Challenge-Based Learning assisted by gamification on students’ mathematical critical thinking skills and mathematical resilience.

3. RESULTS AND DISCUSSION

3.1. Results

This research was conducted on seventh grade students consisting of two classes. Class VII A as an experimental class with a learning model Challenge Based Learning based on STEM Context assisted by Gamification and class VII G as a control class with a learning model Problem Based Learning. The process of learning activities in these two classes consisted of 6 meetings. At the first meeting was the collection of pretest data on critical thinking skills and an initial questionnaire on mathematical resilience to determine the initial abilities of students in both classes. After the first meeting was carried out, the second to fifth meetings were the learning process with similarity material using different learning models in each class, the last meeting closed with a posttest taking a critical thinking skills test and a final questionnaire on mathematical resilience to determine the effect of learning model Challenge Based Learning based on STEM Context assisted by Gamification with learning model Problem Based Learning on critical thinking skills and mathematical resilience students. The results of the normality and homogeneity tests are presented in the following table.

Tabel 2. Multivariate Normality Test Results

Data	Group	Correlation Coefficient	Information
Pretest	Eksperiment	Henze Zikler $= 0{,}416$ $\mathrm{p-value} = 0{,}518$	Normal
	Control	Henze Zikler $= 0{,}349$ $\mathrm{p-value} = 0{,}689$	Normal
Posttest	Eksperiment	Henze Zikler $= 0{,}723$ $\mathrm{p-value} = 0{,}084$	Normal
	Control	Henze Zikler $= 0{,}368$ $\mathrm{p-value} = 0{,}639$	Normal

Tabel 3. Univariate Normality Test Results

Data	Group	Variable	Correlation Coefficient	Information
Pretest	Eksperiment	Critical Thinking Skills	$\mathrm{p-value} = 0{,}952$	Normal
		Mathematical Resilience	$\mathrm{p-value} = 0{,}0597$	Normal
	Control	Critical Thinking Skills	$\mathrm{p-value} = 0{,}9648$	Normal
		Mathematical Resilience	$\mathrm{p-value} = 0{,}8612$	Normal
Posttest	Eksperiment	Critical Thinking Skills	$\mathrm{p-value} = 0{,}0672$	Normal
		Mathematical Resilience	$\mathrm{p-value} = 0{,}1182$	Normal
	Control	Critical Thinking Skills	$\mathrm{p-value} = 0{,}6347$	Normal
		Mathematical Resilience	$\mathrm{p-value} = 0{,}07261$	Normal

Tabel 4. Multivariate Homogeneity Test Results

Data	Correlation Coefficient	Information
Pretest	$\mathrm{chi-square} = 4{,}5915$ & $\mathrm{p-value} = 0{,}2043$	Homogeneous
Posttest	$\mathrm{chi-square} = 2{,}5178$ & $\mathrm{p-value} = 0{,}4721$	Homogeneous

Tabel 5. Univariate Homogeneity Test Results

Variabel	Data	Correlation Coefficient	Information
Critical Thinking Skills	*Pretest*	$F = 0{,}0817$ & $p-value = 0{,}776$	Homogeneous
	Posttest	$F = 0{,}7519$ & $p-value = 0{,}3894$	Homogeneous
Mathematical Resilience	*Pretest*	$F = 1{,}1084$ & $p-value = 0{,}2968$	Homogeneous
	Posttest	$F = 3{,}2263$ & $p-value = 0{,}0777$	Homogeneous

Based on tables 2 through 5, it can be concluded that all data are normal and homogeneous; therefore, hypothesis testing can be conducted. Descriptive statistics for mathematical critical thinking skills and mathematical resilience before and after the treatment are presented in table 6.

Table 6. Descriptive Statistics of Critical Thinking Skills and Mathematical Resilience.

Variable	Group	*Pretest*	*Posttest*
Critical Thinking Skills	Experiment	42,07	87,65
	Control	40,02	72,71
Mathematical Resilience	Experiment	71,83	83,46
	Control	72,24	77,13

In general, both groups possessed relatively similar initial abilities. Following the treatment, both groups showed improvement; however, the improvement in the experimental class was greater than that in the control class regarding both critical thinking skills and mathematical resilience. The results of the average difference test before treatment are presented in the table 7.

Table 7. Multivariate Test Results of Pretest Data.

Effect	T^2	F_{count}	F_{table}
Hotelling's Trace	0,65106	0,31992	3,16

This means that there is no difference in the average before treatment between Challenge Based Learning based on STEM Context assisted by Gamification (experimental class) and problem based learning (control class) on critical thinking skills and mathematical resilience.

Table 8. Multivariate Test Results of Posttest Data.

Effect	T^2	F_{count}	F_{table}
Hotelling's Trace	104,026	51,1164	3,16

This means that there is an average difference after treatment between Challenge Based Learning based on STEM Context assisted by Gamification (experimental class) and problem based learning (control class) on critical thinking skills and mathematical resilience. The results of the independent t test are presented in the following table.

Table 9. Independent Sample T-Test Results.

Variabel	T_{count}	T_{table}
Critical Thinking Skills	7,39227	1,671
Resiliensi Matematis	6,41557	1,671

Based on the table, it can be concluded that the critical thinking skills data shows that Challenge-Based Learning, based on a STEM context and supported by gamification, has a greater impact on students' critical thinking skills than Problem-Based Learning. Meanwhile, the mathematical resilience data shows that Challenge-Based Learning, based on a STEM context and supported by gamification, has a greater impact on students' mathematical resilience than Problem-Based Learning. The results of the effect size test are presented in the table 10.

The table 10 shows that the effect size of the STEM context-based Challenge-Based Learning model with gamification on critical thinking skills was 1.90868, which is in the high category. Meanwhile, for mathematical resilience, the effect size was 1.65649, which is in the high category.

Table 10. Effect size test using Cohen's d formula

Model	Variabel	Effect Size	Category
STEM Context-Based Challenge-Based Learning with Gamification	Critical Thinking Skills	1,908	High
	Mathematical Resilience	1,656	High

3.2. Discussion

3.2.1 Critical Thinking Skills

Research results indicate that the implementation of STEM Context-Based Challenge-Based Learning (CBL) enhanced by gamification yields superior outcomes regarding mathematical critical thinking skills compared to Problem-Based Learning (PBL). These findings are supported by multivariate test results showing a significant difference between the experimental and control groups post-intervention, and are further reinforced by independent samples t-test results and a high effect size value. The findings suggest that instruction integrating authentic challenges, STEM contexts, and gamification not only produces statistically significant differences but also delivers a substantial practical impact on the development of students' critical thinking skills. The improvement in critical thinking skills within the experimental class is closely linked to the core characteristics of Challenge-Based Learning, which positions students as problem solvers by engaging them in challenges rooted in real-life situations. Unlike instruction focused solely on solving textbook problems, CBL encourages students to identify issues, analyze relevant information, design alternative solutions, implement those solutions, and reflect on the outcomes. This process enables students to construct knowledge through authentic learning experiences, ensuring that cognitive activity extends beyond mere concept recall to encompass analysis, evaluation, and decision-making. These characteristics align with the Challenge-Based Learning framework developed by Johnson et al. (2009) and the implementation guidelines proposed by Nichols et al. (2016), both of which emphasize that challenge-based learning fosters active student engagement in solving real-world problems.

The figure 1 dan 2 shows an example of a student's answer to problem number 2 from two examples of students in the control class. The student's answers indicate that the student's interpretation, analysis, evaluation, and inference skills are poor. In the interpretation indicator, the student is able to articulate and illustrate how the problem is applied in a pictorial form. In the image analysis indicator, 30 students were able to write the problem-solving steps correctly and completely, while in the image analysis indicator, 31 students wrote the problem-solving steps incorrectly. In the evaluation stage, the student also used inappropriate strategies in calculations or explanations and wrote correct conclusions. In the inference indicator, the student did not write a conclusion.

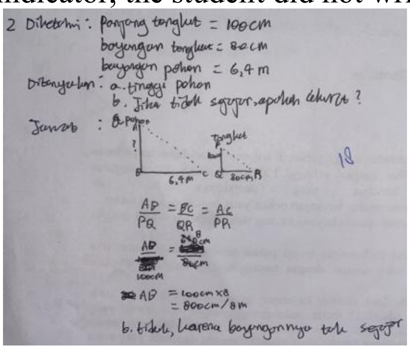

Figure 1. Answer to Test Question Critical Thinking Skills of Control Class Students

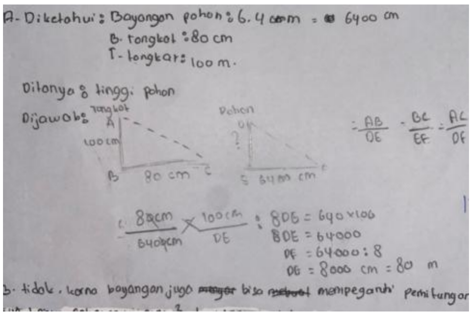

Figure 2. Answer to Test Question Critical Thinking Skills of Experiment Class Students

An analysis of each indicator revealed improvements across all aspects of critical thinking in both groups; however, the gains observed in the experimental class were greater than those in the control class. The interpretation aspect showed the highest level of achievement. This suggests that utilizing STEM contexts relevant to daily life made it easier for students to comprehend the information presented in the problems before determining a solution strategy. Authentic contexts enabled students to connect prior experiences with the mathematical concepts being studied, thereby making the process of understanding the problem more meaningful. According to Beers (2011), STEM-based learning is designed to integrate various disciplines in solving real world problems, thereby enhancing students' ability to interpret the information they gather.

Significant improvement was also observed in the analysis aspect. During instruction, students were encouraged to identify relationships between variables, select the most appropriate strategies, and discuss various potential solutions with their group members. These activities accustomed students to evaluating multiple alternatives before reaching a final decision. Unlike conventional instruction, which tends to focus on procedural solutions, the discussion process inherent in Challenge-Based Learning (CBL) provided students with greater scope to develop systematic mathematical reasoning.

The evaluation aspect also showed substantial improvement in the experimental class. This occurred because generated solutions were not immediately accepted as final answers; instead, they underwent a process of verification and collective reflection. At this stage, students compared different solution strategies, assessed the accuracy of the procedures employed, and identified any remaining errors. Such reflective activities are a key characteristic of Challenge-Based Learning, enabling students to develop the ability to evaluate arguments more objectively (Nichols et al., 2016). In challenge-based learning, conclusions are not provided directly by the teacher but are instead constructed through exploration and discussion. Consequently, students learn to formulate generalizations based on data and logical reasoning. This process fosters reflective thinking skills, which constitute a key indicator of critical thinking (Facione, 2011).

These findings align with the research of Hidayat et al. (2022), who reported that Challenge-Based Learning effectively enhances students' critical thinking skills through STEM-based problem solving. However, the present study offers a broader contribution by not only implementing Challenge-Based Learning but also integrating STEM contexts and gamification into a single instructional design. The integration of these three components creates a more interactive learning environment, providing students with greater opportunities to explore ideas, engage in discussions, receive immediate feedback, and revise their problem-solving strategies.

The superior performance of the experimental class was also influenced by the implementation of gamification via Nearpod. Throughout the learning process, students encountered progressive challenges, immediate feedback, rewards, and interactive activities that boosted their engagement at every stage. This approach encouraged students to actively explore various solution alternatives rather than simply following procedures prescribed by the teacher. Baldrich et al. (2023) and Khaldi et al. (2023) explain that gamification enhances intrinsic motivation, participation, and student engagement through the application of educationally designed game elements. Similarly, a study by Febriansah et al. (2024) demonstrates that gamification provides a more engaging learning experience, thereby encouraging students to take a more active role in constructing knowledge.

In addition to boosting learning motivation, the use of Nearpod provides immediate feedback on student answers, allowing them to quickly identify any errors made. This rapid feedback enables students to adjust their problem-solving strategies before misconceptions can take root. Bailey et al. (2021) explain that digital learning platforms like Nearpod enhance student interaction, collaboration, and participation by offering a variety of real-time learning activities. These conditions foster a more active, student-centered learning environment, ultimately contributing to the development of mathematical critical thinking skills.

Overall, the research findings indicate that the improvement in critical thinking skills stems not only from the use of Challenge-Based Learning as an instructional model but also from the synergy of STEM contexts, authentic problem-solving, group collaboration, reflection, and gamification all of which heighten student engagement throughout the learning process. The integration of these components creates a more meaningful learning experience compared to the Problem-Based Learning approach used in the control group, thereby enabling a more optimal development of mathematical critical thinking skills.

3.2.2 Mathematical Resilience, Implications, and Research Contributions

In addition to enhancing mathematical critical thinking skills, the results of this study indicate that the implementation of STEM Context-Based Challenge-Based Learning (CBL) supported by gamification has a more positive impact on students' mathematical resilience compared to Problem-Based Learning. This conclusion is reinforced by a high effect size value, indicating that the impact of the intervention is not merely statistically significant but also practically meaningful in bolstering students' resilience when confronting various difficulties in learning mathematics.

The improvement in mathematical resilience observed in the experimental class stems from the nature of Challenge-Based Learning, which affords students the opportunity to directly experience the processes of discovery, experimentation, refinement, and evaluation regarding the solutions to the problems presented. Throughout this process, students are not steered toward obtaining instant answers; instead, they are encouraged to view errors as a natural component of the learning journey. Such learning experiences cultivate the belief that success is attainable through sustained effort. This aligns with Masten's (2001) concept of resilience which posits that resilience develops through positive adaptation when facing challenges as well as the perspective of Reivich and Shatté (2002), who emphasize that resilient individuals can manage difficulties constructively without losing the motivation to continue growing.

The improvement in the "value" aspect indicates that students have gained a greater appreciation for the importance of mathematics in daily life. This shift is largely attributable to the use of STEM contexts, which link mathematical concepts to real-world phenomena, helping students realize that mathematics is not merely a collection of formulas but a tool for analyzing and resolving various life challenges. When students perceive the direct utility of the concepts they are studying, their intrinsic motivation to learn also increases. According to Beers (2011), STEM-based learning is designed to enable students to integrate crossdisciplinary knowledge to solve authentic problems, thereby enhancing the relevance of learning to real-life needs.

The improvement in the "struggle" aspect demonstrates that students have become more capable of persevering when faced with complex problems. During instruction, students are encouraged to explore various solution alternatives without the fear of making mistakes. Opportunities for discussion, receiving feedback from both teachers and peers, and refining solution strategies create a learning experience that fosters self-confidence. This aligns with the perspective of Yeager and Dweck (2012), who posit that students with a growth mindset view difficulties as opportunities for development rather than indicators of incompetence. Consequently, a learning environment that supports exploration and reflection plays a crucial role in cultivating mathematical resilience.

The "growth" aspect also showed greater improvement in the experimental class compared to the control class. This indicates that the instruction not only enhanced learning outcomes but also transformed students' beliefs regarding their own mathematical abilities. At each stage of Challenge-Based Learning, students have the opportunity to reflect on their thought processes, document their solutions, and receive feedback on the solutions they have developed. These activities help students realize that mathematical ability evolves through practice, experience, and continuous improvement. These findings support the incremental mindset theory proposed by Yeager and Dweck (2012), which explains that the belief in the capacity for growth enhances students' perseverance and resilience when facing academic challenges.

The enhancement of mathematical resilience in this study was also influenced by the use of gamification via the Nearpod platform. Various game elements such as progressive challenges, point systems, immediate feedback, and interactive activities created a learning atmosphere that was both enjoyable and challenging. Such a learning environment helps alleviate students' mathematics anxiety by providing opportunities to retry after experiencing failure. Baldrich et al. (2023) explain that gamification can boost student motivation, engagement, and persistence through the application of game elements in instruction. Systematic reviews conducted by Khaldi et al. (2023) and Febriansah et al. (2024) further indicate that gamification offers a more engaging learning experience, encouraging students to be more active and confident, and less likely to give up when faced with academic tasks.

These findings align with research by Sari et al. (2020), which reported that Challenge-Based Learning enhances students' academic resilience by presenting challenges that require active engagement throughout the learning process. However, the present study makes a broader contribution by integrating STEM contexts and gamification into the Challenge-Based Learning framework. This integration creates a more comprehensive learning experience that goes beyond mere problem-solving; it fosters interdisciplinary thinking, boosts learning motivation, and builds student resilience in the face of mathematical difficulties.

Overall, the results demonstrate that the improvement of critical thinking skills and mathematical resilience does not occur in isolation but rather reinforces one another. Students capable of critical thinking tend to be more confident in evaluating problem-solving strategies, while those with mathematical resilience are better able to persevere when tackling challenging problems. This relationship indicates that successful mathematics learning depends not only on conceptual mastery but also on students' psychological readiness to navigate complex learning processes. Therefore, instruction should be designed to develop both competencies simultaneously. From the perspective of mathematics education, this study implies that teachers need to design instruction that goes beyond a mere focus on achieving learning outcomes; it should also provide authentic learning experiences that foster exploration, collaboration, reflection, and the use of digital technology. The integration of Challenge-Based Learning, STEM contexts, and gamification demonstrates how these three components complement one another in creating an active, meaningful, and student-centered learning environment. Consequently, this instructional model offers a relevant alternative strategy to support the implementation of 21st-century learning.

This study also makes an empirical contribution to the development of technology based mathematics instruction. Unlike previous studies that generally examined the relationship between Challenge-Based Learning and either critical thinking skills or mathematical resilience in isolation (Hidayat et al., 2022; Sari et al., 2020), this research integrates Challenge-Based Learning, STEM contexts, and Nearpod-based gamification into a single instructional design, subsequently evaluating their simultaneous impact on two crucial 21st-century competencies. Thus, the study expands the empirical evidence regarding the effectiveness of challenge-based learning supported by digital technology in enhancing the quality of mathematics education.

Overall, the research findings indicate that integrating Challenge-Based Learning, STEM contexts, and gamification creates a more interactive, contextual, and collaborative learning environment, thereby positively influencing students' critical thinking skills and mathematical resilience. These findings reinforce the view that 21st-century mathematics instruction needs to integrate cognitive, affective, and technological aspects into a cohesive instructional design; this ensures that students are not only capable of solving mathematical problems but also possess the resilience to continue learning and growing when faced with increasingly complex challenges.

4. CONCLUSION

This study demonstrates that the implementation of gamification-assisted, STEM-context Challenge-Based Learning yields superior outcomes regarding the mathematical critical thinking skills and mathematical resilience of 7th-grade students compared to Problem-Based Learning. The integration of authentic challenges, STEM contexts, and gamification fosters a more active, collaborative, and meaningful learning experience; this encourages students to analyze problems in greater depth, evaluate various solution alternatives, and sustain their motivation when encountering difficulties in mathematics learning.

These findings indicate that critical thinking skills and mathematical resilience can be developed simultaneously through instruction that integrates cognitive, affective, and technological aspects into a single instructional design. Consequently, gamification-assisted, STEM-context Challenge-Based Learning serves as a relevant instructional alternative for supporting the development of 21st-century competencies in mathematics education.

This research also makes an empirical contribution to the advancement of technology-based mathematics instruction by integrating Challenge-Based Learning, STEM contexts, and gamification into a comprehensive instructional design. Future research is encouraged to examine the model's effectiveness across different educational levels, mathematical topics, and learner characteristics, as well as to explore its impact on other 21st-century competencies, such as problem-solving skills, creativity, and mathematical communication.

REFERENCES

Bailey, J., Schneider, C., & Vander Ark, T. (2021). *Modern Learning Platforms: Transforming Education Through Digital Tools*. *Journal of Educational Technology*, 18(2), 56–67.

Baldrich, K., Pérez-García, C., Domínguez-Oller, J. C., & de Amo Sánchez-Fortún, J. M. (2023). *Gamified Experiences in Educational Academic Contexts: A Systematic Review.* Qualitative Research in Education, 12(2), 97–115.

Beers, S. Z. (2011). 21st Century Skills: Preparing Students for THEIR Future. *Technological Horizons in Education Journal*, 38(7), 42-48.

Facione, P. A. (2011). *Critical thinking: What it is and why it counts* (2011 ed.). Insight Assessment.

Facione, P. A. (2013). Critical Thinking: What It Is and Why It Counts. Insight Assessment.

Febriansah, A. T., Syaifuddin, A., & Soepriyanto, Y. (2024). *Gamification Developments in Education.* Scholaria: Jurnal Pendidikan dan Kebudayaan, 14(2), 177-186.

Fisher, D., & Frey, N. (2017). *Rigorous Reading: 5 Access Points for Comprehending Complex Texts*. ASCD.

Hidayat, R., Prasetyo, Z. K., & Maulana, A. (2022). The Effectiveness of Challenge Based Learning on Students' Critical Thinking Skills in STEM-Based Science Learning. *Jurnal Pendidikan Sains Indonesia*, 10(1), 11–19.

Johnson, L., Smith, R., Smythe, J., & Varon, R. (2009). *Challenge Based Learning: An approach for our time*. The New Media Consortium.

Khaldi, A., Bouzidi, R., & Nader, F. (2023). *Gamification of e-learning in higher education: A systematic literature review.* Smart Learning Environments, 10(1), Article 10.

Krajcik, J., & Blumenfeld, P. (2014). Project-Based Learning. *In The Cambridge Handbook of the Learning Sciences* (pp. 317-334). Cambridge University Press.

Masten, A. S. (2001). *Ordinary magic: Resilience processes in development*. American Psychologist, 56(3), 227–238. https://doi.org/10.1037/0003-066X.56.3.227.

Nichols, M., Cator, K., & Torres, M. (2016). *Challenge Based Learning: A Classroom Guide for Implementation.* Digital Promise.

Nichols, M., Cator, K., Torres, M., & Digital Promise and The Challenge Institute. (2016). *Challenge Based Learner User Guide*. 59

Partnership for 21st Century Skills. (2019). *Framework for 21st century learning*. http://www.battelleforkids.org/networks/p21/frameworks-resources

Raivo, R., & Ardiansyah, A. S. (2023). *Telaah Model Challenge Based Learning Bernuansa STEM terhadap kemampuan berpikir kreatif*. PRISMA UNNES.

Reivich, K., & Shatté, A. (2002). *The Resilience Factor: 7 Keys to Finding Your Inner Strength and Overcoming Life's Hurdles*. Broadway Books.

Sari, N. L., Fitriyani, R., & Yuliana, D. (2020). Meningkatkan Resiliensi Akademik Siswa melalui Challenge Based Learning. *Jurnal Psikologi Pendidikan dan Konseling*, 6(2), 124–132.

Sekaran, U., & Bougie, R. (2019). *Research methods for business: A skill-building approach* (8th ed.). Wiley.

Yeager, D. S., & Dweck, C. S. (2012). Mindsets that Promote Resilience: When Students Believe that Personal Characteristics Can Be Developed. *Educational Psychologist*, 47(4), 302-314.