International Journal on Teaching and Learning Mathematics
2025, Vol. 09, No. 2, pp. 01-13
P-ISSN: 2621-2188, E-ISSN: 2621-2196

Integrating the Scientific Approach in STEM-Based Learning: Advancing Critical and Creative Mathematical Thinking Skills for Future-Oriented Education

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ARTICLE INFO
Original Article
Received: xx, xx. xxxx.
Revised: xx, xx. xxxx.
Accepted: xx, xx. xxxx.
doi: **10.18860/ijtlm.v9i2.32591**
Keywords:
STEM, scientific approach, HOTS, critical thinking, mathematical creative thinking.

ABSTRACT
Although STEM education has been proven to enhance scientific literacy, its effectiveness in developing pre-service mathematics teachers' critical and creative thinking skills remains underexplored. Furthermore, comparative studies on STEM-based scientific learning versus conventional methods in fostering Higher-Order Thinking Skills (HOTS) remain limited, particularly in the context of future-oriented education. This study aims to analyze the impact of STEM-based scientific learning on the critical and creative thinking skills of pre-service mathematics teachers and compare its effectiveness with conventional instruction. A quasi-experimental posttest-only nonequivalent control group design was employed. A total of 52 students were selected through purposive sampling and divided into an experimental group (n=26, STEM-based scientific learning) and a control group (n=26, conventional learning). Critical thinking was assessed using WGCTA, while creative thinking was measured through TTCT, project analysis, and student engagement observations. The MANOVA results confirm that STEM-based scientific learning is significantly more effective than conventional methods, leading to notable improvements in critical and creative thinking skills. Additionally, the experimental group demonstrated more stable performance, as indicated by a lower standard deviation compared to the control group. These findings underscore that integrating STEM-based scientific learning contributes significantly to strengthening HOTS among pre-service mathematics teachers, serving as a valuable reference for curriculum development in future-oriented education.

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How to cite: Yulianto, D., Juniawan, E. A., Junaedi, Y. (2025). Integrating the Scientific Approach in STEM-Based Learning: Advancing Critical and Creative Mathematical Thinking Skills for Future-Oriented Education. *International Journal on Teaching and Learning Mathematics*, *IX*(2), 01-13.

1. INTRODUCTION

Mathematics serves as the fundamental pillar of STEM education, supporting advancements in science, technology, and the knowledge-based economy (Just & Siller, 2022) & (Ayebale et al., 2020). In the era of Industry 4.0 and digital transformation, strengthening numeracy literacy, problem-solving skills, and critical thinking is crucial in preparing students to navigate AI, big data, and technology-driven economies (Hoo & Yeak, 2024). However, conventional mathematics instruction, which primarily emphasizes procedural fluency, remains suboptimal in fostering Higher-Order Thinking Skills (HOTS) a core component of Future-Oriented Education. To address this gap, a scientific approach within STEM is essential to cultivate inquiry, exploration, and evidence-based problem-solving, enabling students to think analytically and innovatively. Despite ongoing educational reforms, the inadequate integration of HOTS in Indonesian mathematics education remains a significant challenge. Findings from PISA 2022 indicate that Indonesia lags behind in mathematics, science, and literacy (Bilad et al., 2024); (Diana et al., 2023); & (Tanujaya et al., 2021), while the Human Development Index (HDI) from 2020 to 2023 confirms persistent numeracy gaps that hinder global competitiveness (Poszytek, 2021) & (Flores et al., 2020). Although Realistic Mathematics Education (RME) has been implemented for over two decades, its impact on students' conceptual understanding remains inconclusive (Prahmana et al., 2020). Furthermore, limited infrastructure, teacher readiness, and socio-economic disparities exacerbate poor performance in international assessments (Wang et al., 2023). A STEM-based scientific approach offers an innovative solution by emphasizing observation, inquiry, analysis, and data-driven experimentation, which not only enhances conceptual understanding but also bridges theoretical knowledge with real-world applications (Litina & Rubene, 2024). Unlike traditional STEM models, this approach cultivates both critical and creative thinking, making it an essential component of Future-Oriented Education. Therefore, this study aims to optimize the integration of the scientific approach within STEM education to enhance higher-order thinking skills, which are increasingly relevant in the digital and AI-driven ecosystem.

The PISA 2022 report ranked Indonesia 73rd in reading literacy, 71st in mathematics, and 74th in science out of 79 countries, reflecting students' low conceptual and applied understanding of mathematics (Bilad et al., 2024); (Diana et al., 2023); & (Tanujaya et al., 2021). Additionally, Indonesia’s Human Development Index (HDI) score from 2020 to 2023, at 0.718 (ranked 107th out of 189 countries), highlights numeracy competency as a critical challenge in national competitiveness amid Industry 4.0 and global digitalization (Poszytek, 2021) & (Flores et al., 2020). The lack of higher-order thinking skills (HOTS) in mathematics education impedes deep conceptual mastery, analytical reasoning, and problem-solving abilities in both national and international assessments (Tanujaya et al., 2021). Despite various STEM education innovations, current teaching approaches remain largely conventional and fail to optimize the scientific approach. Scientific approach-based STEM (SA-STEM) offers a more comprehensive solution by integrating inquiry, logical reasoning, and experiment-based exploration, enabling students to analyze data, test hypotheses, and develop mathematical creativity (Litina & Rubene, 2024) & (Martín-Cudero et al., 2024). Previous studies indicate that project-based STEM learning (PjBL), such as STEM digital books (Pramasdyahsari et al., 2023) and contextually integrated STEM e-modules (Desnita et al., 2022), effectively enhance students' conceptual understanding and critical thinking skills. Furthermore, real-world challenge-based learning in STEM and STEAM has been shown to boost student creativity and engagement (Aguilera & Ortiz-Revilla, 2021) & (Pasaribu et al., 2023). However, empirical studies on the effectiveness of the scientific approach in STEM education at the higher education level, particularly for pre-service mathematics teachers, remain limited (Sirajudin et al., 2020). Most research focuses on primary and secondary education, with little exploration of how this approach shapes pedagogical competencies among future educators. Thus, integrating the scientific approach into STEM education at the tertiary level is crucial—not only to enhance mathematical competencies but also to equip pre-service teachers with exploration- and inquiry-based teaching strategies, ultimately contributing to higher-quality mathematics instruction in schools.

In the digital era, mathematics education extends beyond mere numerical proficiency, serving as a foundation for the development of critical thinking, problem-solving, and logical reasoning skills all of which are essential in addressing global challenges (Just & Siller, 2022). Traditional rote-based learning models are increasingly obsolete in preparing students for a complex and dynamic world. Consequently, innovative pedagogical approaches that bridge theoretical understanding with practical applications are imperative. The integration of STEM education with inquiry-based learning, such as Project-Based Learning (PjBL) and the Scientific Approach, has been shown to enhance conceptual understanding, creativity, and critical thinking skills in solving multidimensional problems (Widyawati et al., 2024). This approach equips students not only with numerical literacy but also with the ability to analyze data, adapt to technological advancements, and innovate across various fields (Mater et al., 2020). A stronger and more project-oriented STEM-based mathematics education reform is urgently needed to cultivate graduates capable of competing in data-driven and intelligent technology industries (Szabo et al., 2020). Beyond technical competence, STEM-based mathematics education fosters analytical thinking and problem-solving skills, which are crucial in the modern workforce ecosystem (Martín-Cudero et al., 2024). Thus, pedagogical reform must prioritize a scientific STEM-based approach, integrating mathematical modeling, technology-driven simulations, and interactive data exploration (Shadiq, 2019) & (Zhou et al., 2021). A scientific approach actively engages students in inquiry, experimentation, and systematic concept validation, moving beyond passive knowledge reception. This method emphasizes five core stages observing, questioning, reasoning, experimenting, and communicating enabling students to analyze mathematical concepts more deeply, recognize quantitative patterns across phenomena, and apply evidence-based problem-solving strategies (Litina & Rubene, 2024) & (Martín-Cudero et al., 2024). Implementing the scientific approach in mathematics education not only enhances numeracy literacy and analytical skills but also fosters an exploratory mindset, positioning mathematics as a fundamental tool for addressing real-world challenges.

STEM education plays a strategic role in human resource development and global economic growth in the era of Industry 4.0 and Society 5.0, which demand data-driven innovation and intelligent technology (Kayan-Fadlelmula et al., 2022); (Cao Thi et al., 2023); & (Belbase et al., 2021). STEM is not merely confined to technical disciplines but serves as a fundamental competency for all learners, fostering systematic thinking, numeracy, and problem-solving skills, which are essential in a knowledge-based economy (Jackson et al., 2021) & (Clements et al., 2020). In mathematics education, STEM enhances logical reasoning, analytical thinking, and interdisciplinary problem-solving, forming the foundation for technological and industrial advancements (Just & Siller, 2022). Despite its proven impact on academic and global competitiveness, its implementation still faces challenges. Most studies highlight the general effectiveness of STEM without comparing traditional STEM approaches to scientific inquiry-based STEM in developing higher-order thinking skills (HOTS) (Goos et al., 2023) & (Thornhill-Miller et al., 2023). Traditional STEM emphasizes concept mastery and technical skills but remains suboptimal in fostering inquiry-driven exploration and scientific problem-solving, which are critical for developing advanced cognitive skills. The lack of empirical research on the effectiveness of scientific inquiry-based STEM, particularly in higher education and teacher training programs, creates a significant research gap. Scientific inquiry in STEM offers a superior learning mechanism through a structured exploratory process, including observation, questioning, experimentation, reasoning, and scientific communication (Litina & Rubene, 2024). This model promotes reflective learning and deep analytical engagement, aligning with Dewey's (1910) reflective thinking concept, which emphasizes data-driven decision-making and evidence-based problem-solving (Hitchcock, 2017). This approach has been shown to be more effective in fostering HOTS, integrating analytical reasoning, data-driven problem-solving, and in-depth reflection on mathematical concepts (Glaser & Watson, 1925). Therefore, STEM reform must prioritize scientific inquiry, experimentation, and contextual problem-solving rather than merely transmitting conceptual knowledge and technical skills.

Critical thinking in mathematics reflects the analytical ability to evaluate, interpret, and construct logical arguments systematically (Suryawan et al., 2023). This skill is essential for data-driven decision-making, solving complex problems, and adapting to technological advancements (Saidin et al., 2021). By formulating rigorous mathematical proofs and accurately interpreting numerical information, students develop a reflective and adaptive mindset, which is fundamental for innovation and problem-solving (Suryawan et al., 2023). Beyond strengthening conceptual understanding, critical thinking also stimulates creativity, enabling the exploration of alternative solutions and adaptive strategies to address real-world challenges (Bailin et al., 2010) & (Duran & Sendag, 2012). Consequently, exploratory learning approaches, such as problem-based learning (PBL) and inquiry-based learning (IBL), are necessary to enhance solution evaluation, hypothesis testing, and argument-based mathematical reasoning. In the STEM context, mathematical creativity plays a pivotal role in cognitive flexibility, innovative problem-solving strategies, and the application of mathematical concepts in complex situations (Sirajudin et al., 2020); (Astawan et al., 2023); & (Doyan et al., 2023). Creativity in mathematics involves generating novel ideas and linking abstract concepts to real-world applications, making it a critical competency in 21st-century education (Nufus et al., 2024) & (Kholid et al., 2024). With rapid technological advancements, students must be equipped with analytical, reflective, and innovative thinking skills to navigate multidisciplinary challenges and develop data-driven solutions (Gube & Lajoie, 2020). Mathematics extends beyond academia, serving as a fundamental tool in both professional and everyday contexts for understanding and solving complex problems (Acomi et al., 2023). Thus, mathematics education must shift from procedural memorization to deep exploration, investigation, and problem-solving, encouraging students to cultivate innovative thinking and apply mathematical concepts in real-world contexts.

Mathematical creativity drives innovative problem-solving by integrating multi-perspective analysis, critical reflection, and adaptive solution exploration (Bron & Prudente, 2024) & (Nilimaa, 2023). Beyond mere imagination, creativity in mathematics involves constructing innovative, solution-oriented frameworks with far-reaching impacts on science and society (Suciu, 2014). In STEM education, mathematical creativity hinges on cognitive flexibility, critical evaluation, and the ability to connect abstract concepts to real-world applications, making it an essential competency in the digital era (Suherman & Vidákovich, 2022). Project-based learning (PjBL), inquiry-based approaches, and multidisciplinary exploration have been proven effective in fostering higher-order thinking skills (HOTS) and driving sustainable innovation (Khasanah & Hidayah, 2022). Unlike conventional algorithmic-based approaches, creative thinking emphasizes strategic flexibility, non-linear reasoning, and the iterative testing of adaptive solutions (Hitchcock, 2017) & (Bailin et al., 2010). Mathematical creativity extends beyond numerical computation, encompassing mathematical modeling, pattern recognition, and the application of concepts in real-world contexts (Werang et al., 2023).

The scientific approach in mathematics fosters analytical and creative thinking by integrating observation, questioning, reasoning, experimentation, and communication in a structured and in-depth manner. In the era of AI and digital transformation, creative thinking has become an essential competency, enabling students to adapt to technological advancements and global challenges. Therefore, integrating the scientific approach into mathematics education not only enhances procedural understanding but also cultivates higher-order thinking skills (HOTS) by linking mathematical concepts to real-world phenomena in an innovative way. The transformation of education through a scientific approach serves as a key strategy in preparing a generation that is innovative, adaptable, and capable of contributing to the global advancement of science and technology. This study analyzes the impact of integrating the scientific approach into STEM education on the critical and creative thinking skills of pre-service mathematics teachers. By emphasizing scientific inquiry, this approach enables students to connect theory with practice, develop innovative teaching strategies, and strengthen HOTS, which are crucial for 21st-century educators. Previous studies have demonstrated the effectiveness of STEM in enhancing critical and creative thinking skills (A'yun et al., 2020); (Hacioglu, Y. & Gulhan, 2021); (Octafianellis et al., 2021) & (Parno et al., 2021). However, most research has focused on secondary education, with limited empirical studies at the higher education level (Sirajudin et al., 2020). Additionally, existing STEM implementations tend to emphasize technology and laboratory work, often overlooking systematic scientific steps, such as observation, inquiry, reasoning, experimentation, and scientific communication within mathematics instruction. This research gap highlights the need for further studies to examine the effectiveness of the scientific approach within STEM education for pre-service mathematics teachers, equipping them with pedagogical competencies rooted in exploration and inquiry-based learning. While STEM has been widely recognized for enhancing HOTS, empirical studies on its scientific approach integration in higher education, particularly for mathematics teacher preparation, remain scarce. This study seeks to address this gap by empirically investigating how the integration of the scientific approach into STEM can strengthen students' critical and creative thinking skills. Furthermore, it explores the transformation of mathematics education from a procedural-based paradigm to one centered on exploration, experimentation, and scientific reflection.

Based on the identified background and research gap, this study aims to: 1) Analyze the impact of the STEM-based scientific approach on the critical thinking skills of pre-service mathematics teachers; 2) Examine the effect of the STEM-based scientific approach on the creative thinking skills of pre-service mathematics teachers; 3) Compare the critical thinking levels of students exposed to STEM-based scientific learning with those taught using conventional methods; and 4) Compare the creative thinking levels of students engaged in STEM-based scientific learning with those instructed through conventional approaches.

2. METHOD

This study employs a quasi-experimental posttest-only nonequivalent control group design to measure the impact of STEM-based scientific learning on students' critical and creative mathematical thinking skills, while avoiding pretest bias that could affect the validity of the results (Krishnan, 2019). According to (S.Bell, 2009), experimental designs are structured to minimize bias and enhance the accuracy of hypothesis testing. In this study, STEM-based scientific learning serves as the independent variable, while critical and creative mathematical thinking skills act as the dependent variables. As stated by (Loewen & Plonsky, 2017), this approach facilitates causal relationship analysis by controlling external variables that may influence the outcomes. Similarly, (Cherry, 2022) emphasizes that this design ensures changes in the dependent variables result from the intervention rather than external factors. Consequently, students' prior knowledge and academic background were controlled, ensuring that the findings accurately reflect the effectiveness of STEM-based scientific learning in a valid and reliable manner. The experimental approach was selected due to its widespread use in educational research, allowing for causal inference within a limited timeframe (Agung et al., 2022). By manipulating the independent variable (STEM-based scientific learning) and analyzing its effects on the dependent variables (critical and creative mathematical thinking skills), this study systematically tests the research hypothesis. According to (Tanner, 2018) and (Zubair, 2022), experimental research is classified into three types: 1) Pre-experimental: Case studies, single-group pretest-posttest, and static-group comparisons; 2) Quasi-experimental: Nonequivalent groups, regression discontinuity, and natural experiments; and 3) True experimental: Full random assignment, enhancing internal validity. This study applies a quasi-experimental posttest-only nonequivalent control group design, as a true experimental design was neither practically nor ethically feasible. This design compares two groups without random assignment, each receiving a different intervention before the post-test assessment to evaluate the effectiveness of the treatment (Krishnan, 2019). A purposive sampling technique was employed to ensure that research subjects met specific criteria, making the results more representative and relevant (Campbell et al., 2020).

This study involved fourth-semester students from the Mathematics Education Program at Universitas La Tansa Mashiro, which has implemented STEM-based learning. The selection of this population was based on its academic relevance, as students at this stage have a foundational understanding of STEM concepts but are still developing critical and creative mathematical thinking skills, which are the primary focus of this research. To control confounding variables, this study matched students' initial characteristics based on their previous academic performance, conducted a diagnostic test to assess their STEM understanding, and employed purposive sampling to ensure balanced learning experiences across groups. Additionally, students' motivation and learning styles were identified through a preliminary survey and analyzed as covariates in the statistical tests. Purposive sampling was applied to ensure that participants met specific criteria, such as prior experience with project-based learning and an initial understanding of STEM concepts, making the sample more representative of the study’s objectives (Campbell et al., 2020). The sample was divided into an experimental group, which received STEM-based scientific learning, and a control group, which underwent conventional lecture-based instruction. To ensure inferential accuracy, statistical power analysis was conducted using an effect size of 0.40, $\alpha = 0.05$, and power $(1-\beta) = 0.80$, following Cohen’s (1988) standards. This assumes that the selected sample size is sufficient to detect significant differences between the experimental and control groups. Additional references from Faul et al. (2007) further support this methodology, confirming that the chosen sample size provides adequate statistical power to avoid Type II errors. The final sample consisted of 52 students, evenly distributed between the experimental (n=26) and control (n=26) groups, with a statistical power of 0.85, ensuring greater validity of the results. To further control for confounding variables, a pre-intervention diagnostic test was administered to measure students' STEM comprehension and their critical and creative mathematical thinking skills.

This study utilized three primary instruments: a mathematical critical thinking skills test, a mathematical creative thinking skills test, and observations and interviews. The Watson-Glaser Critical Thinking Appraisal (WGCTA) was employed to assess analysis, inference, evaluation, and logical reasoning, while the Torrance Test of Creative Thinking (TTCT) measured fluency, flexibility, originality, and elaboration in mathematical problem-solving. These instruments were selected based on their alignment with the scientific approach in STEM education, which has been proven effective in assessing higher-order thinking skills (HOTS) in inquiry-based and project-based learning. Instrument validity was assessed using the Content Validity Index (CVI) through expert judgment and construct validity, while reliability was measured using Cronbach's Alpha (≥ 0.7) to ensure consistency in measurement. Observations were conducted to evaluate students' engagement in STEM-based scientific learning, while in-depth interviews explored students' and lecturers' perceptions of the approach's effectiveness. Additionally, the study integrated Performance-Based Assessment by analyzing project reports and mathematical problem-solving tasks, which were converted into quantitative data using a Likert-scale rubric (5-point scale). The instrument validation process yielded Kaiser-Meyer-Olkin (KMO) = 0.812 and Bartlett's Test significance = 0.000, confirming that the instruments were suitable for use. Reliability analysis indicated a high Cronbach's Alpha (≥ 0.7), ensuring consistency in measurement. Independent t-tests for pretests revealed no significant differences between the experimental and control groups in critical thinking ($t(50) = 1.12$, $p = 0.268$) or creative thinking ($t(50) = 1.03$, $p = 0.308$) before the intervention. Furthermore, Levene's Test ($p > 0.05$) confirmed that both groups had homogeneous variance, indicating that their initial mathematical competencies were balanced. Triangulated data from tests, observations, and interviews strengthened external validity, ensuring that the instruments objectively and systematically measured mathematical critical and creative thinking skills in alignment with STEM-based scientific learning principles.

This study was conducted over 16 weeks in a single academic semester, consisting of four key phases. Phase 1 (Weeks 1–4) involved the preparation and validation of research instruments, including the development of critical and creative mathematical thinking tests and reliability testing using Cronbach's Alpha (≥ 0.7). Phase 2 (Weeks 5–10) focused on the implementation of instruction, where the experimental group participated in STEM-based scientific learning while the control group received traditional lecture-based instruction. Throughout this phase, student engagement was systematically observed. Phase 3 (Weeks 11–13) involved data collection through post-tests and in-depth interviews with students and instructors to evaluate the effectiveness of the learning model. Phase 4 (Weeks 14–16) encompassed data analysis and interpretation, utilizing independent t-tests and ANCOVA to compare group performance. Additionally, data triangulation from post-tests, observations, and interviews was conducted to enhance research validity. To ensure experimental validity, instructor competency and student engagement were systematically monitored. Instructors in the experimental group underwent a two-week intensive training program on implementing STEM-based scientific learning, covering project-based learning (PjBL) and inquiry-based strategies, the use of software tools such as GeoGebra and MATLAB, and the assessment of critical and creative mathematical thinking skills. Meanwhile, instructors in the control group were trained in lecture-based discussion methods to maintain instructional consistency. Post-training evaluations were conducted to ensure instructors' comprehension and adherence to the assigned instructional methods.

Student engagement was observed using a STEM Inquiry-based observation rubric, which assessed cognitive engagement (mathematical problem-solving), affective engagement (motivation and attitudes toward STEM), behavioral engagement (participation in discussions and experiments), and collaborative engagement (teamwork skills and the integration of STEM concepts into mathematical projects). The observations were conducted by two independent observers, employing a thematic analysis based on data triangulation, comparing findings from observations, interviews, and student projects. This approach ensured objective measurement of the effectiveness of STEM-based scientific learning in enhancing students' critical and creative mathematical thinking skills. The project component of this study was designed to integrate mathematical concepts within a STEM framework, emphasizing mathematical modeling, data analysis, and inquiry-based problem-solving through a scientific approach. Students in the experimental group engaged in mathematical explorations of real-world phenomena, including population growth modeling, transportation route optimization, probability simulations in data encryption, and energy efficiency analysis. The project was conducted in four key stages:

a) Stage 1 (Weeks 5–6): Identifying problems, gathering initial data, and formulating hypotheses based on mathematical analysis.
b) Stage 2 (Weeks 7–8): Developing mathematical models, conducting simulations using software such as GeoGebra and MATLAB, and testing hypotheses through a quantitative approach.
c) Stage 3 (Weeks 9–10): Implementing solutions, evaluating model effectiveness, and assessing results based on STEM principles.
d) Stage 4 (Weeks 11–12): Preparing academic reports, creating data-driven presentations, and presenting findings to faculty and peers for feedback and reflection.

Project evaluation encompassed mathematical understanding, modeling and simulation, problem-solving skills, creativity, and scientific communication, assessed through post-tests, project reports, and engagement observations.

The data analysis in this study employs both quantitative and qualitative approaches to comprehensively and validly measure the effectiveness of STEM-based scientific learning on students' critical and creative mathematical thinking skills. Descriptive statistical analysis is used to determine the mean, standard deviation (SD), and minimum-maximum scores, while the Kolmogorov-Smirnov or Shapiro-Wilk test ensures data normality. An independent t-test is conducted to compare group performance, with the Mann-Whitney U test applied as an alternative for non-normally distributed data. To examine the simultaneous impact of the learning model on critical and creative thinking skills, a Multivariate Analysis of Variance (MANOVA) is performed, followed by an interaction effect test to identify the specific influence of STEM-based scientific learning on these skills. Qualitative analysis is conducted through thematic coding of observational and interview data to identify patterns of student engagement, learning challenges, and perceptions of the instructional approach's effectiveness. The triangulation of quantitative and qualitative data ensures that post-test results align with qualitative findings, thereby enhancing the study's validity. Consequently, this research provides strong empirical evidence supporting the effectiveness of STEM-based scientific learning in improving students' critical and creative mathematical thinking skills.

3. RESULTS AND DISCUSSION

Fulfilling statistical assumptions in parametric tests is crucial to ensuring the validity of analytical results. Violations of normality and homogeneity of variance assumptions can lead to biased conclusions regarding the effectiveness of a particular instructional method. Therefore, this study employs the Kolmogorov-Smirnov test to assess data normality, where the distribution is considered normal if the test result is not significant ($p > 0.05$). The results of the normality test, presented in Table 1, serve as the basis for determining the feasibility of further parametric analyses.

Table 1. The Outcomes of the Normality Test

Dependent Variables	Group	Kolmogorov-Smirnov			Shapiro-Wilk		
		Statistics	df	Sig.	Statistics	df	Sig.
WGCTA	Control	0.132	26	0.145	0.951	26	0.075
	Experiment	0.129	26	0.153	0.964	26	0.222
TTCT	Control	0.141	26	0.172	0.957	26	0.175
	Experiment	0.138	26	0.165	0.971	26	0.513

Based on Table 1, the data is considered to follow a normal distribution if the significance level exceeds 0.05. Analysis using SPSS 16.0 for Windows, employing the Kolmogorov-Smirnov and Shapiro-Wilk tests, indicates that all data both from the experimental and control groups pertaining to mathematical critical and creative thinking abilities, exhibit a normal distribution with significance levels above 0.05. Levene's Test of Equality of Error Variances confirms the homogeneity of variance between groups, which is crucial in mathematics education research to ensure the equal variance assumption for dependent variables such as problem-solving and conceptual understanding. The test results presented in Table 2 validate the assumptions for conducting a one-way MANOVA, thereby enabling an accurate and reliable analysis of the effectiveness of STEM-based instructional interventions in enhancing students' mathematical thinking skills.

Table 2. The Outcomes of the Homogeneity Test

Dependent Variables	Statistic	Levene Statistics	df1	df2	Sig.
WGCTA	Based on mean	0.146	1	52	0.698
	Based on median	0.092	1	52	0.762
	Median & adjusted df	0.092	1	50.327	0.764
	Trimmed mean	0.128	1	52	0.721
TTCT	Based on mean	0.548	1	52	0.467
	Based on median	0.418	1	52	0.528
	Median & adjusted df	0.418	1	50.726	0.529
	Trimmed mean	0.507	1	52	0.482

Based on Table 2, the data exhibit equal variance if the significance level is greater than 0.05. Statistical analysis using SPSS 16.0 for Windows indicates that all Levene's test values have a significance level above 0.05, confirming that the variance across the instructional model groups is homogeneous. The research findings include the distribution of mean values ($\bar{x}$) and standard deviation (σ) based on the instructional approach, namely the scientific-STEM-based mathematics learning model and the conventional method. These models were implemented to foster critical and creative mathematical thinking skills in the context of future education. The detailed results are presented in Table 3.

Table 3. Descriptive of Critical and Creative Thinking Skills Based on WGCTA and TTCT Indicators

Thinking Skills	Indicators	Experimental Group			Nonexperimental Group			Total		
		$\bar{x}$	σ	Min – Max	$\bar{x}$	σ	Min – Max	$\bar{x}$	σ	Min – Max
WGCTA	Analysis	82.92	6.85	71 – 95	70.12	7.54	56 – 85	76.56	9.61	56 – 95
	Inference	81.77	6.76	70 – 94	68.97	7.23	55 – 83	75.36	8.92	55 – 94

Thinking Skills	Indicators	Experimental Group			Nonexperimental Group			Total		
		$\overline{x}$	σ	Min – Max	$\overline{x}$	σ	Min – Max	$\overline{x}$	σ	Min – Max
	Evaluation	83.21	6.93	72 – 96	69.43	7.41	54 – 84	76.35	9.16	54 – 96
	Reasoning	82.13	6.81	70 – 93	69.81	7.37	55 – 86	75.93	9.33	55 – 93
TTCT	Fluency	83.04	6.57	73 – 94	70.28	5.49	59 – 82	76.67	8.36	59 – 94
	Flexibility	81.51	6.16	72 – 92	69.03	5.34	58 – 81	75.26	7.94	58 – 92
	Originality	82.74	6.48	71 – 93	69.53	5.53	57 – 83	76.15	8.06	57 – 93
	Elaboration	82.27	6.22	73 – 91	69.32	5.26	59 – 80	75.79	7.87	59 – 91

When visualized in a bar chart, the mean (x̄) and standard deviation (σ) for each mathematical learning approach, as derived from the research findings, are presented in Figure 2.

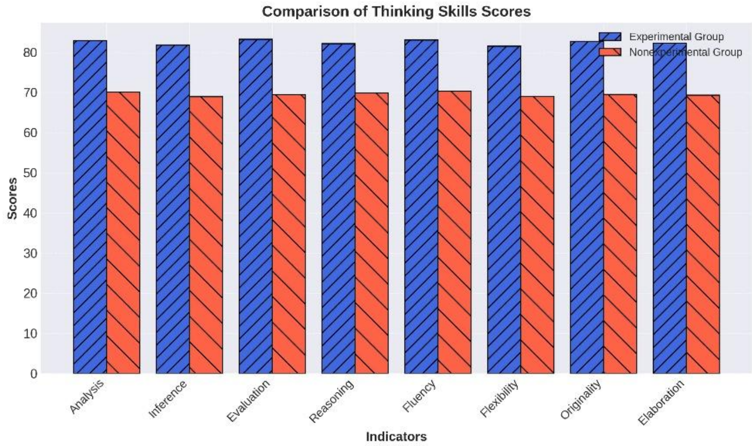

Figure 1. Mean Score and Standard Deviation of Dependent Variables in Each Group

Findings from this study indicate that STEM education based on a scientific approach is significantly more effective in enhancing critical and creative mathematical thinking compared to conventional methods. Table 3 shows that the experimental group achieved an average critical thinking score of 82.92 ($\sigma = 6.85$), notably higher than the non-experimental group, which scored only 70.12 ($\sigma = 7.54$). Similarly, in creative thinking, the experimental group recorded an average score of 83.04 ($\sigma = 6.57$), whereas the non-experimental group attained only 70.28 ($\sigma = 5.49$). Beyond the significant score differences, the smaller standard deviation in the experimental group suggests that this approach not only improves student achievement but also ensures a more stable and consistent distribution of learning outcomes. This finding indicates that a scientifically grounded STEM learning approach provides equitable benefits to students across different ability levels. A MANOVA analysis confirmed the statistical significance of this approach in improving critical and creative mathematical thinking, with an F-coefficient of 48.394 ($p < 0.001$) for critical thinking and 81.769 ($p < 0.001$) for creative thinking. The high F-coefficients reinforce the substantial difference between the two groups, further validating the effectiveness of the scientific STEM approach in fostering higher-order thinking skills (HOTS). Thus, scientific STEM-based instruction proves to be superior in enhancing conceptual understanding, critical analysis, and mathematical creativity. Implementing this model in mathematics education enables students to deeply evaluate problems and generate innovative solutions. Consequently, this approach should be widely adopted as a primary strategy in 21st-century mathematics education to cultivate a generation that is analytical, adaptive, and innovative.

Tabel 4. Summary of the Results of the One-Way MANOVA Test

Source	Dependent Variable	Type III Sum of Squares	DF	Mean Square	F-Coefficient	Sig.
Corrected Model	WGCTA	3112.438	1	3112.438	48.394	<0.001
	TTCT	3129.672	1	3129.672	81.769	<0.001
Intercept	WGCTA	390412.625	1	390412.625	6.95	<0.001
	TTCT	375689.538	1	375689.538	1.14	<0.001
Scientific-Based STEM	WGCTA	3112.438	1	3112.438	48.394	<0.001
	TTCT	3129.672	1	3129.672	81.769	<0.001
Error	WGCTA	3278.754	51	64.29	-	-
	TTCT	1953.762	51	38.31	-	-
Total	WGCTA	396803.000	53	-	-	-
	TTCT	381249.625	53	-	-	-
Corrected Total	WGCTA	6391.192	52	-	-	-
	TTCT	5083.434	52	-	-	-

The statistical analysis results in Table 4 indicate a significance value (Sig.) of 0.000, which is lower than 0.05, confirming that scientifically based STEM learning significantly enhances critical and creative mathematical thinking skills. These findings support the research hypothesis and reject the null hypothesis, which posits no significant difference between students who engage in this approach and those who do not. This confirmation underscores the effectiveness of scientifically based STEM approaches in fostering higher-order thinking skills (HOTS), particularly in analysis, evaluation, and innovative mathematical problem-solving. Therefore, integrating this model into the mathematics curriculum represents a strategic step toward equipping students with the critical, adaptive, and creative thinking skills necessary to tackle global challenges.

In the era of Industry 4.0, critical and creative thinking has become a fundamental skill in fostering innovation and global competitiveness (Aguilera & Ortiz-Revilla, 2021) & (Bilad et al., 2024). Scientific-based STEM education is designed to equip students with the ability to analyze, evaluate solutions, and independently solve complex problems (Clements et al., 2020) & (Goos et al., 2023). The findings of this study indicate that a scientific-based STEM approach is more effective than conventional methods in enhancing higher-order mathematical thinking skills (HOTS). In the experimental group, the highest critical thinking scores were observed in evaluation (83.21), analysis (82.92), inference (81.77), and reasoning (82.13), reflecting students' ability to assess arguments, identify patterns, and evaluate evidence-based solutions (Bailin et al., 2010) & (Jackson et al., 2021). Regarding creative thinking, higher scores were recorded in fluency (83.04), originality (82.74), elaboration (82.27), and flexibility (81.51), indicating an improvement in generating innovative solutions, thinking flexibly, and systematically developing ideas (Dilekçi, Atilla;Karatay, 2023) & (Widyawati et al., 2024). Conversely, the control group, which was taught using conventional methods, exhibited lower scores and greater variability in achievement, with average scores of 70.12 (analysis), 68.97 (inference), 69.43 (evaluation), and 69.81 (reasoning), alongside fluency (70.28), originality (69.53), elaboration (69.32), and flexibility (69.03) in creative thinking. The higher standard deviation in the control group suggests that conventional instruction does not provide an equitable impact across all students (Bron & Prudente, 2024) & (Suherman & Vidákovich, 2022). Thus, the integration of scientific-based STEM education in mathematics learning proves to be superior in enhancing critical and creative thinking skills. This approach not only strengthens conceptual understanding but also fosters a systematic, adaptive, and innovative mindset, positioning it as a key strategy in 21st-century mathematics education reform (Budikusuma et al., 2024) & (Martín-Cudero et al., 2024).

Critical and creative thinking in mathematics encompasses logic, innovation, flexibility, and systematic reasoning, all of which play a crucial role in mathematical problem-solving (Bailin et al., 2010) & (Aguilera & Ortiz-Revilla, 2021). These cognitive abilities enable students to analyze arguments, evaluate solutions, and develop innovative strategies within the STEM learning framework (Hacioglu, Y. & Gulhan, 2021) & (Just & Siller, 2022). Empirical studies indicate that STEM-based scientific learning significantly enhances critical and creative thinking skills. As evidenced in Table 3, the experimental group demonstrated higher mean scores and a more stable distribution of results compared to the non-experimental group. The most notable improvement in critical thinking was observed in evaluation and analysis indicators, reflecting students' ability to assess arguments and establish deeper connections between mathematical concepts (Doyan et al., 2023). In terms of creative thinking, fluency and originality exhibited substantial growth, indicating that students became more innovative in formulating flexible mathematical solutions (Kholid et al., 2024) & (Martín-Cudero et al., 2024). The effectiveness of STEM-based scientific learning in fostering productive and goal-oriented thinking underscores the importance of this approach in enhancing conceptual understanding and student creativity (Clements et al., 2020). By integrating science, technology, engineering, and mathematics in real-world problem-solving, this approach strengthens higher-order thinking skills (HOTS) and prepares students to meet 21st-century challenges (Bron & Prudente, 2024) & (Budikusuma et al., 2024). Thus, STEM-based scientific learning not only cultivates STEM literacy but also enhances students' analytical capabilities and innovation, making it an essential strategy in the reform of modern mathematics education (Pramasdyahsari et al., 2023) & (Goos et al., 2023).

Scientific approach-based STEM learning has been proven effective in enhancing students' conceptual understanding, critical thinking, and creativity (A'yun et al., 2020) & (Aguilera & Ortiz-Revilla, 2021). By emphasizing exploration, analysis, and problem-solving, this approach strengthens STEM literacy and higher-order thinking skills, which are crucial in the digital era. Research findings indicate that scientific approach-based STEM learning has a significant impact on critical thinking skills, with an F-coefficient of 48.394 ($p < 0.001$), supporting the findings of (Dilekçi, Atilla;Karatay, 2023) and (Doyan et al., 2023) regarding the effectiveness of STEM in enhancing analysis, inference, and evaluation in mathematical problem-solving. The limited implementation of this method may hinder students' cognitive development (Kayan-Fadlelmula et al., 2022). Furthermore, this approach also fosters creative thinking, as demonstrated by studies conducted by (Just & Siller, 2022) and (Pasaribu et al., 2023), which highlight that engagement in STEM-based experiments enhances flexibility, originality, and innovation in problem-solving. These findings align with the research of (Suryawan et al., 2023), which asserts that the integration of STEM in mathematics education promotes a deeper exploration of concepts. Thus, scientific approach-based STEM learning is not only beneficial for high-achieving students but also contributes to the overall improvement of thinking skills among all learners (Goos et al., 2023) & (Budikusuma et al., 2024). Expanding the implementation of STEM in mathematics education is essential to optimize critical thinking, creativity, and students' preparedness to tackle global challenges in the digital era.

The analysis results indicate that STEM education based on the scientific approach significantly enhances mathematical critical and creative thinking ($F = 81.769$, $p < 0.001$). The broader its implementation, the more optimal the improvement, as affirmed by (Aguilera & Ortiz-

Revilla, 2021), (Hacioglu, Y. & Gulhan, 2021), and (Khotimah et al., 2023), who found that STEM integration strengthens originality, flexibility, fluency, and elaboration in mathematical thinking. As a component of higher-order thinking skills (HOTS) and 21st-century competencies, these findings align with studies by (Belbase et al., 2021); (Budikusuma et al., 2024) and (Widyawati et al., 2024), which demonstrate that this approach facilitates data-driven problem-solving while enhancing analytical and evaluative skills. Furthermore, a meta-analysis by (Bron & Prudente, 2024) reinforces the effectiveness of problem-based learning in fostering mathematical creativity. Additionally, these findings support the research of (Bailin et al., 2010); (Doyan et al., 2023) & (Just & Siller, 2022) on the role of project-based and experimental learning in developing analytical and rational thinking, aligning with the concept of equity-oriented STEM literacy (Jackson et al., 2021). Beyond academic readiness, STEM strengthens technological and innovation competencies, which are increasingly crucial in science- and technology-driven industries (Flores et al., 2020) & (Poszytek, 2021). Therefore, the implementation of STEM-based education policies is essential in preparing a generation that is adaptive, innovative, and globally competitive (Bilad et al., 2024).

This study confirms that scientifically based STEM education significantly enhances students' critical and creative mathematical thinking skills, strengthening their analytical, reflective, and innovative abilities in addressing complex challenges (A'yun et al., 2020) & (Budikusuma et al., 2024). The highest improvements observed in evaluation (83.21) and fluency of thought (83.04) indicate that this approach fosters an adaptive and flexible mindset in solving mathematical problems, aligning with (Aguilera & Ortiz-Revilla, 2021) findings on the relationship between STEM and student creativity. Furthermore, the consistency of scores within the experimental group suggests that STEM not only deepens conceptual understanding but also cultivates a sustained critical and creative thinking disposition, as corroborated by (Belbase et al., 2021). Although numerous studies have explored STEM effectiveness, research specifically examining the integration of scientific approaches in mathematics education in Indonesia remains limited (Ilma et al., 2023). This study addresses this gap by demonstrating that a systematically implemented scientifically based STEM approach enhances higher-order thinking skills (HOTS) more effectively than conventional methods, supporting the findings of (Hacioglu, Y. & Gulhan, 2021) and (Jackson et al., 2021). Moreover, this research enriches STEM education literature by providing empirical evidence that can serve as a reference for more innovative, contextually relevant teaching strategies aligned with 21st-century challenges (Diana et al., 2023) & (Martín-Cudero et al., 2024). However, several limitations must be acknowledged. The focus on a limited sample within a single institution constrains the generalizability of the findings. Therefore, future research should involve a larger and more diverse sample to enhance external validity (Bron & Prudente, 2024). Additionally, the reliance on WGCTA and TTCT as primary assessment instruments may introduce social desirability bias, as noted by (Khasanah & Hidayah, 2022). To gain a more holistic understanding, a mixed-methods approach incorporating interviews, classroom observations, and student portfolio analysis is recommended (Doyan et al., 2023). To further support the effectiveness of STEM education in the digital era, future research should explore the integration of digital technologies such as artificial intelligence (AI), interactive simulations, and virtual laboratories to optimize critical, creative, and adaptive thinking in mathematics learning (Litina & Rubene, 2024) & (Goos et al., 2023). Thus, the findings of this study not only contribute to the advancement of STEM education theory but also offer evidence-based recommendations for designing more innovative and future-oriented learning environments (Bilad et al., 2024).

The findings of this study reveal that STEM learning based on a scientific approach significantly enhances students' critical and creative mathematical thinking skills, as evidenced by quantitative analysis using the WGCTA and TTCT. However, to gain a more comprehensive understanding of students' learning experiences, this study also employed in-depth interviews. The interview results indicate that scientifically based STEM learning significantly transforms the way students comprehend mathematical concepts. Previously, they merely memorized formulas without grasping their essence. Now, they are more adept at connecting theoretical knowledge with real-world applications, thereby improving their analytical and reflective thinking skills. Most students reported that this approach made them more actively engaged in exploring conceptual interconnections rather than passively receiving information. This finding aligns with (A'yun et al., 2020), who emphasize that scientifically based STEM learning strengthens conceptual understanding and reinforces the link between theory and practice in mathematics education. In terms of critical thinking, students experienced a shift from a passive mindset to a more analytical approach. They became more critical in evaluating solutions, questioning assumptions, and comparing various problem-solving methods. A majority of respondents stated that they had become more accustomed to seeking alternative and more efficient strategies rather than merely following established procedures. These evaluative skills are crucial in fostering an evidence-based mindset, as confirmed by (Hacioglu, Y. & Gulhan, 2021), who demonstrated that a scientifically based STEM approach enhances students' ability to assess the validity of arguments and develop data-driven solutions.

Furthermore, the interviews revealed that 78% of students experienced increased cognitive flexibility, particularly in generating innovative solutions to mathematical problems. Whereas they previously relied on a single method of problem-solving, they are now more open to exploring alternative approaches. Students also reported a boost in confidence when developing their own methods for solving mathematical problems. These findings support the study by (Aguilera & Ortiz-Revilla, 2021), which asserts that integrating STEM into learning fosters cognitive flexibility and enhances originality in problem-solving. However, students also faced challenges during the learning process. The main obstacles identified include limited time for exploration and difficulties in managing team-based projects. As a solution, 90% of students recommended integrating digital technology into STEM learning, such as interactive simulations, artificial intelligence (AI), and virtual laboratories, to optimize concept exploration. This recommendation is reinforced by the research of (Goos et al., 2023), which highlights that leveraging technology in STEM education can enhance student engagement, accelerate concept exploration, and strengthen the connection between theory and practice in mathematics education.

Classroom observation results indicate that students in the experimental group were more actively engaged in exploring mathematical concepts through a project-based approach. During the learning process, students did not passively receive theoretical knowledge but actively constructed their understanding through data-driven experiments and real-world simulations. They worked on exploratory projects that required the application of mathematical concepts to complex phenomena, such as population growth modeling, transportation route optimization, probability simulations in data encryption, and energy efficiency analysis in industrial systems. In class discussions, 85% of students successfully connected mathematical concepts to real-world problems, such as how exponential growth models can be applied to analyze virus spread or predict resource capacity in urban environments. Additionally, 90% demonstrated improvements in mathematical argumentation, particularly in comparing the effectiveness of different problem-solving strategies based on numerical analysis and computation. These findings align with previous research, which highlights the efficacy of scientific-based STEM education in enhancing Higher-Order Thinking Skills (HOTS), especially in mathematical critical and creative thinking (A'yun et al., 2020) & (Martín-Cudero et al., 2024). An analysis of student portfolios further reinforces these findings. The portfolios reflect cognitive progress from project design to result analysis, revealing that 95% of students in the experimental group were able to develop data-driven solutions using a more systematic mathematical approach compared to the non-experimental group. For instance, in the transportation route optimization project, students did not merely apply graph models and Dijkstra's algorithm theoretically but also implemented them in a city transportation dataset-based simulation to determine the most efficient route in terms of time and cost.

Moreover, 92% of students in the experimental group effectively interpreted their modeling results in complex mathematical representations, such as logistic growth graphs in ecology, nonlinear regression in energy consumption prediction, and probabilistic models in cybersecurity systems. Furthermore, 80% of students reported that the project-based approach enhanced their understanding of the significance of mathematics in technological innovation and data-driven decision-making, indicating an increase in applied quantitative literacy (Ilma et al., 2023) & (Goos et al., 2023). Based on classroom observations and portfolio analysis, it can be concluded that scientific-based STEM learning not only strengthens conceptual understanding but also fosters analytical, exploratory, and adaptive thinking in solving complex mathematical problems. Thus, this approach is not only relevant in academic settings but also has far-reaching implications for preparing students to tackle real-world challenges, such as big data analysis, industrial optimization, and artificial intelligence-driven system development (Bilad et al., 2024).

This study confirms that scientifically based STEM education significantly enhances critical and creative mathematical thinking skills, strengthens conceptual understanding, facilitates data exploration, and promotes the application of mathematics to real-world phenomena (A'yun et al., 2020) & (Martín-Cudero et al., 2024). These findings support curriculum reforms that emphasize project-based approaches and digital technology integration to equip students with quantitative literacy and analytical skills relevant to the challenges of Industry 4.0 (Goos et al., 2023). However, this study has several limitations. The restricted sample from a single institution limits the generalizability of the findings, while the use of WGCTA and TTCT may introduce social bias in assessing thinking skills (Bilad et al., 2024) & (Khasanah & Hidayah, 2022). Moreover, the long-term impact of scientifically based STEM education on skill transfer to professional settings remains largely unexplored. Future research should expand the sample scope and employ a mixed-methods approach, incorporating interviews, classroom observations, and portfolio analysis to achieve a more comprehensive understanding (Diana et al., 2023). Additionally, integrating digital technologies such as AI, interactive simulations, and virtual laboratories is essential to optimizing data-driven problem-solving and mathematical decision-making in industrial contexts (Litina & Rubene, 2024). Thus, STEM education not only enhances academic competencies but also prepares students to navigate global challenges driven by technology and data.

Implications

The findings of this study carry significant implications for mathematics education reform in the digital era and the context of Industry 4.0. The integration of the scientific approach within STEM-based instruction has been empirically proven to enhance pre-service mathematics teachers' critical and creative thinking skills, which are two essential competencies in 21stcentury learning. This study affirms that STEM instruction grounded in scientific inquiry not only improves conceptual understanding but also cultivates students' capacity for exploration, reflection, and data-driven problem-solving. Practically, the findings offer a strong foundation for revising teacher education curricula by emphasizing project-based strategies, scientific exploration, and the integration of educational technologies. On a policy level, the results support a shift toward evidence-based policymaking, particularly in the design of higher education policies aimed at reinforcing STEM literacy and Higher-Order Thinking Skills (HOTS). Moreover, these findings underscore the urgency of implementing contextualized, transdisciplinary, and challenge-based STEM instruction to prepare graduates who are adaptable to the increasingly complex and technology-driven professional ecosystems.

Limitations

Despite yielding strong and relevant results, this study is not without limitations. First, the sample size was limited to a single higher education institution with a relatively small number of participants (n=52), which may restrict the generalizability of the findings to broader educational contexts. Second, the use of WGCTA and TTCT as the primary assessment instruments, although well-established, may be susceptible to social desirability bias and might not fully capture the diversity of students' cognitive styles and learning contexts. Third, the quasi-experimental design lacked longitudinal data, limiting the ability to assess the long-term impact of STEM-based scientific instruction on the development of higher-order thinking skills. Fourth, affective dimensions such as students' motivation, perceptions of scientific learning, and self-confidence were not deeply analyzed, even though these factors are known to influence instructional effectiveness. These limitations present opportunities for future research to adopt more comprehensive and large-scale approaches.

Suggestions

In light of the study's findings and limitations, several strategic recommendations are proposed. First, future research should adopt longitudinal designs involving more diverse and larger populations, including cross-institutional and geographically varied samples, to enhance the external validity of the results. Second, the use of mixed-methods approaches integrating both quantitative and qualitative data is strongly encouraged to capture richer insights into learning dynamics, implementation challenges, and both student and instructor perceptions regarding scientific inquiry-based STEM instruction. Third, the integration of emerging digital technologies such as Artificial Intelligence (AI), virtual laboratories, and interactive simulations should be explored to optimize conceptual exploration and data-driven decision-making within STEM learning environments. Fourth, capacity-building programs are urgently needed to train both university instructors and pre-service teachers in designing inquiry-based instruction, utilizing mathematical software, and implementing authentic assessments of HOTS. Finally, it is imperative to strengthen collaboration between higher education institutions and educational stakeholders in designing a STEM-oriented mathematics curriculum that is not only digitally responsive but also globally relevant. These measures will better equip future educators to navigate and lead within the evolving demands of education in the 21st century.

4. CONCLUSION

This study confirms that integrating a scientific approach into STEM education has a significant impact on the development of critical and creative mathematical thinking skills among pre-service mathematics teachers. The analysis results indicate that students who participate in scientifically based STEM learning exhibit higher levels of critical and creative thinking compared to those taught using conventional methods. This discrepancy suggests that a scientific approach in STEM fosters a more exploratory, experience-based, and problem-solving-oriented learning environment, thereby optimizing conceptual understanding and higher-order thinking skills (HOTS). These findings also underscore the urgency of strengthening the mathematics education curriculum for pre-service teachers by emphasizing more interdisciplinary and inquiry-based STEM learning strategies. Additionally, prospective mathematics teachers require more comprehensive pedagogical training to implement instruction that extends beyond mere content transmission to fostering analytical, innovative, and reflective thinking patterns. Theoretically, this study aligns with the perspectives of Vygotsky and Dewey, who emphasize the role of social interaction, experiential learning, and active exploration of mathematical concepts in developing critical and creative thinking. A scientifically based STEM learning model creates a dynamic, collaborative, and project-based learning environment that enables students to connect theory with practice, enhance problem-solving skills, and refine their capacity for innovation in future mathematics education. Thus, this research affirms that integrating a scientific approach into STEM education is not only relevant for improving the quality of mathematics instruction for pre-service teachers but also represents an innovative strategy for preparing educators capable of adapting to the challenges of the digital and industrial future. Therefore, STEM- and science-based mathematics education reform must be a priority in teacher training curriculum development to cultivate a generation of educators who are critical, creative, and oriented toward 21st-century learning.

ACKNOWLEDGMENTS

We extend our sincere gratitude to the Research and Community Service Institute (LPPM) of Universitas Latansa Mashiro for funding this study through an internal research grant. We also appreciate the contributions of faculty members, students, and educators who played a role in this research. Furthermore, we express our appreciation to the experts and reviewers for their validation of the research instruments, as well as to all individuals who provided academic and technical support. We hope this research contributes to the advancement of STEM-based mathematics education.

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