Vol. 9, No.1, 2026, pp. 212-219
DOI: https://doi.org/10.32698/02259

GLOBAL ECONEDU

Contents lists available at Journal Global Econedu

Journal of Educational and Learning Studies

ISSN: 2655-2760 (Print) ISSN: 2655-2779 (Electronic)

Journal homepage: http://jurnal.globaleconedu.org/index.php/jels

Effects of STEM-integrated problem-based learning on mathematical critical thinking and achievement

Liza Marlian, Rayendra Rayendra*), Darmansyah Darmansyah, Fetri Yeni J
Universitas Negeri Padang, Padang, Indonesia

Article Info

Article history:

Received Apr 30th, 2026
Revised May 15th, 2026
Accepted Jun 30th, 2026

Keywords:

STEM,
Problem-based learning,
Mathematical critical thinking,
Learning outcomes

ABSTRACT

This study aims to examine the effectiveness of a STEM-integrated Problem-Based Learning approach in improving students' mathematical critical thinking skills and cognitive learning outcomes in trigonometry. A quantitative quasi-experimental design with a pretest–posttest nonequivalent control group was employed. The sample consisted of 86 eleventh-grade students at SMAN 19 Batam, divided into an experimental group taught using STEM-integrated PBL and a control group taught conventionally. The experimental group achieved higher improvements in mathematical critical thinking skills, with an N-Gain of 43.98%, compared with 20.76% in the control group. Cognitive learning outcomes also improved more strongly in the experimental group, with an N-Gain of 51.81%, compared with 28.77% in the control group. STEM-integrated PBL is effective for enhancing students' critical thinking and cognitive achievement.

Corresponding Author:

Rayendra Rayendra,
Universitas Negeri Padang
Email: rayendra@fip.unp.ac.id

Introduction

Mathematics education plays a fundamental role in developing students' reasoning, analytical thinking, and problem-solving competencies, which are indispensable for success in the twenty-first century. Contemporary mathematics instruction is expected to promote not only procedural proficiency but also students' ability to think critically, evaluate information logically, formulate arguments, and apply mathematical concepts to authentic situations. Mathematical critical thinking has therefore become one of the primary objectives of mathematics education because it enables learners to make reasoned judgments and solve complex problems systematically (Cintamulya & Murtini, 2025; Ramadhani & Nurita, 2023). Nevertheless, empirical evidence indicates that many secondary school students still experience difficulties in higher-order thinking processes, particularly in interpreting mathematical information, constructing logical arguments, and justifying solutions to contextual problems.

Evidence from international large-scale assessments further confirms these challenges. Results from the Programme for International Student Assessment (PISA) consistently demonstrate that students in many developing countries, including Indonesia, perform relatively poorly in mathematical literacy and critical reasoning tasks (Siregar, 2026; Tairas et al., 2024). Most students are capable of performing routine calculations but encounter difficulties when required to interpret contextual problems, explain mathematical reasoning, and transfer conceptual understanding to unfamiliar situations. These findings suggest that mathematics instruction remains predominantly teacher-centered and focuses largely on procedural competence rather than conceptual understanding and critical reasoning (Padmawati et al., 2025; Pertiwi et al., 2024). Consequently, there is a need for innovative instructional approaches that facilitate active engagement and meaningful learning experiences capable of fostering students' higher-order thinking skills.

One instructional model that has received considerable attention is Problem-Based Learning (PBL). PBL positions students as active participants who construct knowledge through inquiry, investigation, and collaborative problem-solving activities. Through authentic problems, students are encouraged to identify relevant information, formulate hypotheses, evaluate alternative solutions, and communicate their reasoning effectively. Previous studies have demonstrated that PBL contributes positively to students' critical thinking abilities, conceptual understanding, and academic achievement by promoting active participation and self-directed learning (Ayubi et al., 2024; Jasmi et al., 2023; Lestari et al., n.d.; Soomro et al., 2025). However, despite these advantages, PBL implementation often encounters limitations in providing interdisciplinary connections and authentic applications that allow students to integrate mathematical concepts with real-world phenomena. Therefore, the effectiveness of PBL may be strengthened through its integration with broader interdisciplinary learning frameworks.

The Science, Technology, Engineering, and Mathematics (STEM) approach has emerged as an innovative educational framework that integrates knowledge and practices across disciplines to solve authentic and complex problems. STEM education emphasizes inquiry, technological literacy, engineering design, and problem-solving through contextual learning experiences (Aslan, 2026; Jannati et al., 2026). Numerous studies have reported that STEM-oriented instruction positively influences students' motivation, creativity, critical thinking, and academic achievement because learners actively investigate and design solutions to practical challenges (Azhari et al., 2025; Wiratman et al., 2023). Moreover, several studies have shown that STEM-integrated learning promotes analytical reasoning and critical thinking through inquiry, collaboration, and interdisciplinary applications (Bahri et al., 2024; Simanjuntak & Purwaningsih, 2024). Nevertheless, empirical studies specifically examining the integration of STEM and PBL in secondary mathematics education remain relatively limited, and evidence concerning their simultaneous effects on mathematical critical thinking and cognitive learning outcomes in trigonometry is still scarce (Daulay & Syefrinando, 2023; Funa et al., 2024).

The practical context of this study also warrants investigation. Preliminary observations conducted at SMAN 19 Batam revealed that students experienced difficulties in understanding trigonometric concepts, particularly the sine and cosine rules, and demonstrated limited abilities to interpret contextual mathematical problems and justify their solutions. Classroom instruction was predominantly characterized by direct explanation and procedural exercises, resulting in passive participation and limited opportunities to develop mathematical reasoning and critical thinking skills (Adhelacahya et al., 2023; Gusman et al., 2023). Furthermore, previous studies have largely concentrated on cognitive achievement alone and have devoted less attention to simultaneously investigating mathematical critical thinking skills and cognitive learning outcomes. This limitation indicates the necessity for empirical studies that comprehensively evaluate the effectiveness of STEM-integrated PBL on multiple dimensions of mathematics learning.

Based on these considerations, the present study aims to examine the effectiveness of a STEM approach integrated with Problem-Based Learning in improving students' mathematical critical thinking skills and cognitive learning outcomes in trigonometry among eleventh-grade students at SMAN 19 Batam. The novelty of this study lies in three aspects. First, it integrates STEM and PBL within the context of secondary-level trigonometry instruction, an area that has received limited empirical attention. Second, it simultaneously investigates two important educational outcomes, namely mathematical critical thinking skills and cognitive learning achievement. Third, it employs a quasi-experimental design to provide empirical evidence regarding the comparative effectiveness of STEM-integrated PBL and conventional mathematics instruction. The findings are expected to contribute to the literature on innovative mathematics pedagogy by providing empirical evidence concerning the role of interdisciplinary, problem-based learning environments in fostering higher-order thinking and meaningful conceptual understanding in mathematics education.

Method

This study employed a quantitative approach using a quasi-experimental method with a pretest–posttest nonequivalent control group design. This design was selected because the participants could not be randomly assigned due to the existing classroom structure and school regulations. The study involved two groups: an experimental group that received instruction through a Science, Technology, Engineering, and Mathematics (STEM) approach integrated with Problem-Based Learning (PBL) and a control group that received conventional mathematics instruction. The intervention was conducted over six instructional meetings on trigonometric topics, particularly the sine rule and cosine rule. In the experimental class, learning activities were organized according to the syntax of STEM-integrated PBL, including problem orientation, problem identification, investigation and information gathering, interdisciplinary exploration through STEM activities, collaborative solution design, presentation of findings, and reflection. Both groups were administered pretests before the intervention and posttests after the completion of the instructional treatment to examine changes in students' mathematical critical thinking skills and cognitive learning outcomes.

The research was conducted at SMAN 19 Batam, Riau Islands, Indonesia, during the 2025/2026 academic year. The population comprised all eleventh-grade students enrolled at the school. The sample was selected using purposive sampling based on the equivalence of students' prior academic abilities and the school's class assignment policy. Preliminary analysis of the pretest scores indicated that the experimental and control groups possessed comparable baseline abilities, with mean scores of 55.83 and 56.45, respectively, for mathematical critical thinking skills and 55.91 and 58.28, respectively, for cognitive learning outcomes. Two classes participated in the study: Class XI.3 served as the experimental group (n = 46), whereas Class XI.8 served as the control group (n = 40). The independent variable was the STEM-integrated PBL approach, while the dependent variables were mathematical critical thinking skills and cognitive learning outcomes. To minimize potential confounding effects, both groups were taught by the same teacher, used identical learning materials and instructional duration, and followed the same learning objectives and assessment procedures.

Data were collected using both test and non-test instruments. Mathematical critical thinking skills were measured through an essay test developed based on Facione's critical thinking indicators, namely interpretation, analysis, inference, evaluation, and explanation. Cognitive learning outcomes were assessed using a 20-item multiple-choice test covering the trigonometric topics of the sine rule and cosine rule. Supporting data were obtained through classroom observations, structured interviews, student response questionnaires, and product assessment rubrics to capture the implementation process and students' learning experiences. Prior to implementation, all instruments underwent expert validation and psychometric analyses. The mathematical critical thinking instrument demonstrated satisfactory content validity and reliability (Cronbach's $\alpha > 0.70$), while all cognitive test items met acceptable criteria for validity, reliability, item difficulty, and discrimination indices. The collected data were analyzed using descriptive statistics, including means and standard deviations, followed by inferential analyses consisting of Shapiro–Wilk normality tests, Levene's homogeneity tests, normalized gain (N-Gain) analyses, and Independent Samples T-Tests. In addition, Cohen's d effect size was calculated to determine the magnitude of the intervention effect and provide a more comprehensive interpretation of the practical significance of STEM-integrated PBL.

Results and Discussions

This study was conducted to examine the effectiveness of the Science, Technology, Engineering, and Mathematics (STEM) approach integrated with the Problem-Based Learning (PBL) model in improving students' Mathematical Critical Thinking Skills (MCTS) and cognitive learning outcomes in trigonometry. The participants consisted of 86 eleventh-grade students from SMAN 19 Batam, divided into an experimental class (n = 46) and a control class (n = 40). Data analysis included descriptive statistics, normalized gain (N-Gain) analysis, prerequisite tests of normality and homogeneity, and hypothesis testing using the Independent Samples T-Test. The results of the analyses are presented in the following tables.

Table 1. Descriptive Statistics and N-Gain Scores of Mathematical Critical Thinking Skills

Class	Test	N	Minimum	Maximum	Mean	SD	Mean N-Gain	N-Gain (%)	Category
Experimental (STEM + PBL)	Pretest	46	39	71	55.83	8.45			
	Posttest	46	49	98	73.54	10.61	0.4398	43.98	Moderate
Control (Conventional)	Pretest	40	39	72	56.45	8.62			
	Posttest	40	43	82	64.63	8.67	0.2076	20.76	Low

Table 1 shows that both groups had relatively similar baseline mathematical critical thinking skills, with pretest mean scores of 55.83 in the experimental group and 56.45 in the control group. Following the intervention, the experimental group achieved a substantially higher posttest mean score (73.54) than the control group (64.63). The experimental group also attained a higher maximum score (98 versus 82). Furthermore, the experimental group demonstrated a moderate improvement, with an N-Gain score of 0.4398 (43.98%), whereas the control group achieved only a low improvement, with an N-Gain score of 0.2076 (20.76%). These findings indicate that STEM-integrated PBL was more effective than conventional instruction in promoting students' mathematical critical thinking skills.

Table 2. Descriptive Statistics and N-Gain Scores of Cognitive Learning Outcomes

Class	Test	N	Minimum	Maximum	Mean	SD	Mean N-Gain	N-Gain (%)	Category
Experimental (STEM + PBL)	Pretest	46	36	73	55.91	8.45			
	Posttest	46	57	94	74.89	9.49	0.5181	51.81	Moderate
Control (Conventional)	Pretest	40	45	72	58.28	7.46			
	Posttest	40	49	84	68.40	8.23	0.2877	28.77	Low

Table 2 indicates that both groups started with relatively comparable cognitive achievement levels, as reflected by pretest mean scores of 55.91 and 58.28 in the experimental and control groups, respectively. After the instructional intervention, the experimental group achieved a higher posttest mean score (74.89) than the control group (68.40) and attained a higher maximum score (94 versus 84). Moreover, the experimental group exhibited a moderate level of improvement, with an N-Gain score of 0.5181 (51.81%), while the control group demonstrated only a low improvement, with an N-Gain score of 0.2877 (28.77%). These results provide evidence that STEM-integrated PBL was substantially more effective than conventional instruction in improving students' cognitive learning outcomes in trigonometry. Figure 1 depicts the trends in mean pretest and posttest scores of the experimental and control groups, thereby providing a visual representation of the learning gains achieved following the implementation of STEM-integrated Problem-Based Learning.

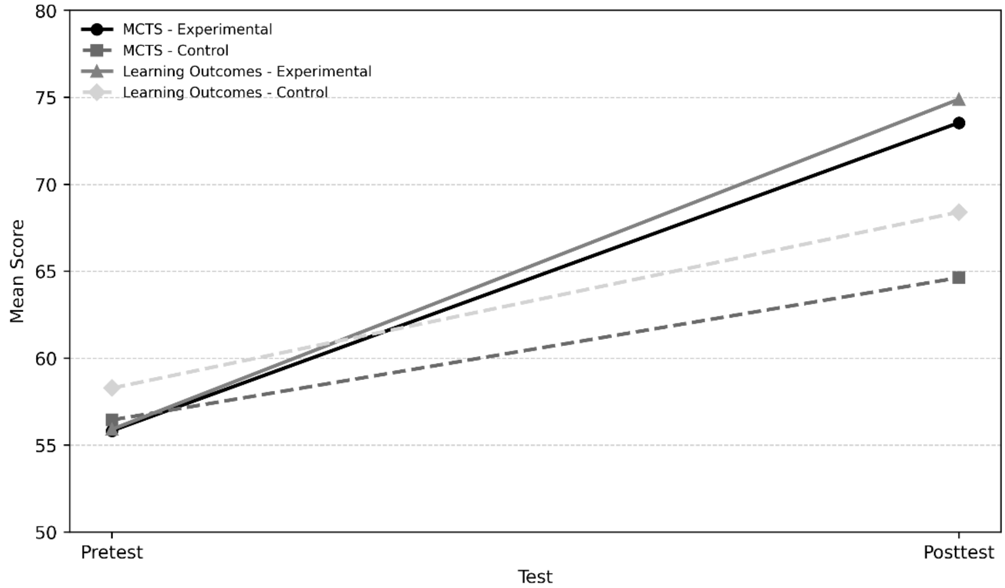

Figure 1. Line Chart of Pretest and Posttest Mean Scores

Table 3. Shapiro–Wilk Normality Test Results

Variable	Group	Statistic	Sig.	Interpretation
Mathematical Critical Thinking Skills	Experimental	0.974	0.157	Normal
	Control	0.968	0.451	Normal
Cognitive Learning Outcomes	Experimental	0.961	0.104	Normal
	Control	0.972	0.214	Normal
N-Gain Scores	Mathematical Critical Thinking Skills	0.976	0.361	Normal
	Cognitive Learning Outcomes	0.969	0.185	Normal

Table 3 demonstrates that all significance values exceeded the threshold of 0.05. Specifically, the significance values ranged from 0.104 to 0.451 across all variables and N-Gain scores. Therefore, all datasets were normally distributed and satisfied the assumptions required for parametric statistical analysis. Consequently, the Independent Samples T-Test could be appropriately employed to test the research hypotheses.

Table 4. Levene's Test of Homogeneity of Variances

Variable	Levene's F	Sig.	Interpretation
Pretest MCTS	0.942	0.485	Homogeneous
Posttest MCTS	0.135	0.715	Homogeneous
N-Gain MCTS	4.488	0.037	Not Homogeneous
Pretest Learning Outcomes	0.018	0.893	Homogeneous
Posttest Learning Outcomes	0.456	0.502	Homogeneous
N-Gain Learning Outcomes	1.018	0.316	Homogeneous

As shown in Table 4, most datasets exhibited homogeneous variances, with significance values greater than 0.05. The only exception was the N-Gain score for mathematical critical thinking skills, which yielded a significance value of 0.037, indicating unequal variances between groups. Therefore, hypothesis testing for MCTS was interpreted using the "Equal variances not assumed" criterion, whereas the analysis of cognitive learning outcomes was conducted under the assumption of equal variances.

Table 5. Independent Samples T-Test Results for N-Gain Scores

Variable	Assumption	t	df	Sig. (2-tailed)	Decision
Mathematical Critical Thinking Skills	Equal variances not assumed	-7.481	75.763	0.000	Reject H_0
Cognitive Learning Outcomes	Equal variances assumed	-7.013	84	0.000	Reject H_0

Table 5 shows that both N-Gain scores produced significance values of 0.000, which are lower than the 0.05 significance level. Therefore, the null hypotheses were rejected for both mathematical critical thinking skills and cognitive learning outcomes. The experimental group achieved higher N-Gain percentages in mathematical critical thinking skills (43.98%) and cognitive learning outcomes (51.81%) than the control group, which obtained 20.76% and 28.77%, respectively. These findings confirm that STEM-integrated PBL was significantly more effective than conventional instruction in improving students' mathematical critical thinking skills and cognitive achievement in trigonometry.

The findings showed that STEM-integrated Problem-Based Learning (PBL) improved students' mathematical critical thinking skills more effectively than conventional instruction. Although both groups had comparable baseline abilities (55.83 and 56.45), the experimental group achieved a higher posttest mean score (73.54) than the control group (64.63). This improvement indicates that STEM-integrated PBL facilitated students' interpretation, analysis, evaluation, and explanation of mathematical ideas through authentic and contextual problem-solving activities. These findings support previous studies reporting that STEM-oriented and problem-based learning environments effectively enhance students' critical reasoning and analytical thinking (Condong et al., 2026; Funa, 2026).

The N-Gain analysis further confirmed this improvement. The experimental group achieved a moderate N-Gain score of 0.4398 (43.98%), whereas the control group obtained only 0.2076 (20.76%). Although the gain remained in the moderate category, it was more than twice that of the control group, suggesting that mathematical critical thinking develops progressively through inquiry, collaboration, and interdisciplinary problem-solving. This finding is consistent with previous studies showing that STEM-integrated learning promotes analytical reasoning and higher-order thinking skills (Bahri et al., 2024; Simanjuntak & Purwaningsih, 2024).

The STEM-integrated PBL approach also improved cognitive learning outcomes. The experimental group's mean score increased from 55.91 to 74.89, with an N-Gain of 0.5181 (51.81%), while the control group improved from 58.28 to 68.40, with an N-Gain of 0.2877 (28.77%). Through contextual investigations involving the sine and cosine rules, students actively constructed conceptual understanding rather than merely memorizing formulas. These findings corroborate previous studies indicating that STEM-integrated PBL enhances conceptual understanding and meaningful learning experiences (Nur & Ikhsan, 2024; Zhou et al., 2025; Zulfawati et al., 2022; AlAli, 2024; Azizah et al., 2025; Hebebci & Usta, 2022; Siregar, 2025).

Inferential analyses further demonstrated significant differences between groups in mathematical critical thinking skills ($t = -7.481$, $p < .001$) and cognitive learning outcomes ($t = -7.013$, $p < .001$). The fulfillment of normality and homogeneity assumptions strengthens the validity of these findings and indicates that the observed improvements can reasonably be attributed to the instructional intervention rather than to initial differences between groups (Ahdhianto et al., 2020; Murni et al., 2024).

The findings provide empirical evidence that STEM-integrated PBL simultaneously enhances mathematical critical thinking and cognitive achievement in trigonometry. The study extends previous research by demonstrating the effectiveness of combining STEM and PBL within secondary mathematics education and suggests that contextual and interdisciplinary learning experiences are effective for fostering higher-order thinking and meaningful learning outcomes (Suparman et al., 2022; Susilo et al., 2020; Yohannes et al., 2021; Yolanda, 2019).

Conclusions

This study concludes that the Science, Technology, Engineering, and Mathematics (STEM) approach integrated with Problem-Based Learning (PBL) is more effective than conventional instruction in improving students' mathematical critical thinking skills and cognitive learning outcomes in trigonometry. Students who participated in STEM-integrated PBL demonstrated significantly higher gains in both variables, as evidenced by the moderate N-Gain categories achieved in mathematical critical thinking skills and cognitive achievement. The findings indicate that learning experiences involving authentic problem-solving, interdisciplinary integration, collaborative inquiry, and contextual application of mathematical concepts effectively promote higher-order thinking and conceptual understanding. Therefore, STEM-integrated PBL can be considered an effective pedagogical approach for enhancing students' critical reasoning and academic performance in secondary mathematics education.

References

Adhelacahya, K., Sukarmin, S., & Sarwanto, S. (2023). The impact of problem-based learning electronics module integrated with STEM on students' critical thinking skills. Jurnal Penelitian Pendidikan IPA, 9(7), 4869–4878.

Ahdhianto, E., Marsigit, Haryanto, & Nurfauzi, Y. (2020). Improving fifth-grade students' mathematical problem-solving and critical thinking skills using problem-based learning. Universal Journal of Educational Research, 8(5), 2012–2021. https://doi.org/10.13189/ujer.2020.080539

AlAli, R. (2024). Enhancing 21st century skills through integrated STEM education using project-oriented problem-based learning. Geo Journal of Tourism and Geosites, 53(2), 421–430.

Aslan, S. (2026). Enhancing Science Motivation, Critical Thinking, and Academic Achievement: The Impact of Cooperative Learning-Based STEM Activities on Primary School Students. Çukurova Üniversitesi Eğitim Fakültesi Dergisi, 55(1), 467–517.

Ayubi, M., Rosa, Y., Arthamena, V., Ash-shiddiq, M., & Putri, S. (2024). The Impact of a Problem-Based Learning Model Combined With a Stem Approach on the Critical Thinking Abilities of High School in Buffer Solution. Anatolian Turkish Journal of Education, 6(3), 298–312.

Azhari, R. A., Hidayah, N., Diani, R., & Kalifah, D. R. N. (2025). Bibliometric Analysis of Problem-Based Learning Model with STEM Approach: Critical Thinking Skills of Elementary School Students. ETDC: Indonesian Journal of Research and Educational Review, 5(1), 55–69.

Azizah, F., Waluya, S. B., & Ardiansyah, A. S. (2025). Systematic Review on Critical Thinking through STEM Integrated Learning in Education. International Journal of Education in Mathematics, Science and Technology, 13(6), 1384–1398.

Bahri, M., Susilo, B. E., & Sutarto, H. (2024). Students' critical thinking abilities based on cognitive style in STEM-integrated problem-based learning. Journal of Hunan University Natural Sciences, 51(1).

Cintamulya, I., & Murtini, I. (2025). Optimization of critical thinking by empowering collaboration and communication skills through information literacy-based E-Books: In stem integrated problem-based learning. European Journal of Educational Research, 14(1), 151–166.

Condong, D. M., Sihaloho, M., Thayban, T., Laliyo, L. A. R., Musa, W. J. A., Kurniawati, E., Munandar, H., & Nggole, S. I. (2026). STEM-Integrated Problem-Based Learning as a Cognitively Aligned Framework for Enhancing Critical Thinking in Thermochemistry. Jambura Journal of Educational Chemistry, 8(1), 120–128.

Daulay, H., & Syefrinando, B. (2023). Meta-Analysis of Students' Cognitive Abilities and Critical Thinking Skills Through the STEM Integrated Learning Model. IJER (Indonesian Journal of Educational Research), 8(3),

1–8.
Funa, A. A. (2026). Effectiveness of integrated STEM and problem-based learning in improving students' conceptual understanding in science. Social Sciences & Humanities Open, 13, 102599.
Funa, A. A., Roleda, L. S., & Prudente, M. S. (2024). Integrated science, technology, engineering, and mathematics—problem-based learning—education for sustainable development (I-STEM-PBL-ESD) framework. In A diversity of pathways through science education (pp. 151–172). Springer.
Gusman, T. A., Novitasari, N., & Yulina, I. K. (2023). The Effect of STEM Integrated Problem-Based Learning Model on Students' Critical Thinking Skills on Electrolyte and Non-Electrolyte Solution Materials. Jurnal Penelitian Pendidikan IPA, 9(10), 8911–8917.
Hebebci, M. T., & Usta, E. (2022). The effects of integrated STEM education practices on problem solving skills, scientific creativity, and critical thinking dispositions. Participatory Educational Research, 9(6), 358–379.
Jannati, E. D., Rochman, C., Nurhikmayati, I., & Prasetya, D. (2026). Enhancing Students' Conceptual Understanding through a STEM-Integrated Problem-Based Learning Model. Bio Educatio: The Journal of Science and Biology Education, 11(1), 1–14.
Jasmi, L., Marjuni, M., Pohan, N. R., & Mufit, F. (2023). The Effect of STEM Integrated Science Innovative Learning Model on Students' Critical Thinking Skills: A Meta-Analysis. Jurnal Penelitian Pendidikan IPA, 9(10), 841–848.
Lestari, R. D., Triyanto, T., & Sudiyanto, S. (n.d.). Preliminary Study on The Implementation of STEM-Integrated Problem-Based Learning in Elementary School Education. Social, Humanities, and Educational Studies (SHES): Conference Series, 9(1).
Murni, A., Saragih, S., Anggraini, R. D., & Azzahra, H. (2024). Students' Mathematical Critical Thinking Ability on Polyhedron Subject through Open-Ended Problem-Based Learning. AIP Conference Proceedings, 3235(1). https://doi.org/10.1063/5.0234441
Nur, S., & Ikhsan, J. (2024). Implementation of STEM Integrated Problem Based Learning Model to Improve Problem Solving Skills and Learning Motivation of Grade X Vocational High School Students on the Material of Substances and Their Changes. Jurnal Penelitian Pendidikan IPA, 10(11), 8882–8891.
Padmawati, K., Pertiwi, K. R., Suyanto, S., & Wulan, A. N. (2025). The Impact of STEM Education on Critical Thinking Skills: A Systematic Literature Review. Jurnal Penelitian Pendidikan IPA, 11(12), 43–51.
Pertiwi, N. P., Saputro, S., Yamtinah, S., & Kamari, A. (2024). Enhancing Critical Thinking Skills through STEM Problem-Based Contextual Learning: An Integrated E-Module Education Website with Virtual Experiments. Journal of Baltic Science Education, 23(4), 739–766.
Ramadhani, F. A., & Nurita, T. (2023). Implementation of STEM-Integrated Problem Based Learning to Improve Students' Problem Solving Skills in Liquid Pressure. Jurnal Pendidikan MIPA, 24(1), 349–358.
Simanjuntak, Y. I. W., & Purwaningsih, D. (2024). STEM Integrated Problem Based Learning: The Implementation and Roles in Science Learning. Jurnal Pendidikan MIPA, 25(2), 686–700.
Siregar, T. (2025). The Effect of Problem-Based Learning and STEM-Based E-Modules on Students' Mathematical Problem-Solving Skills. The Effect of Problem-Based Learning and STEM-Based E-Modules on Students' Mathematical Problem-Solving Skills (November 15, 2025).
Siregar, T. (2026). The Effectiveness of a STEM-Based Instructional Unit in Developing Problem-Solving Skills among Students Madrasah Ibtidaiyah.
Soomro, R. B. K., Soomro, A. B., & Memon, I. (2025). Inquiry-based science teaching and its impact on critical thinking and problem-solving skills: A meta-analysis of STEM education.
Suparman, Juandi, D., Martadiputra, B. A. P., Badawi, A., Susanti, N., & Yunita. (2022). Cultivating Secondary School Students' Mathematical Critical Thinking Skills Using Technology-Assisted Problem-Based Learning: A Meta-Analysis. AIP Conference Proceedings, 2468. https://doi.org/10.1063/5.0102422
Susilo, B. E., Darhim, D., & Prabawanto, S. (2020). Critical thinking skills based on mathematical dispositions in problem-based learning. Journal of Physics: Conference Series, 1567(2). https://doi.org/10.1088/1742-6596/1567/2/022101
Tairas, N., Salirawati, D., Suyanta, S., Rohaeti, E., & Haatainen, O. (2024). Building bridges: How integrated STEM with problem-based learning can enhance student critical thinking and learning outcomes in chemistry. Jurnal Pendidikan Sains Indonesia, 12(3), 597–613.
Wiratman, A., Bungawati, B., & Rahmadani, E. (2023). Project-based learning integrated with science, technology, engineering, and mathematics (stem) to the critical thinking skills of students in elementary school. SITTAH: Journal of Primary Education, 4(2), 167–180.
Yohannes, Juandi, D., & Tamur, M. (2021). The Effect of Problem-Based Learning Model on Mathematical Critical Thinking Skills of Junior High School Students: A Meta-Analysis Study. Jurnal Pengukuran Psikologi Dan Pendidikan Indonesia, 10(2), 142–157. https://doi.org/10.15408/jp3i.v10i2.17893
Yolanda, F. (2019). The Effect of Problem Based Learning on Mathematical Critical Thinking Skills of Junior High School Students. Journal of Physics: Conference Series, 1397(1). https://doi.org/10.1088/1742-6596/1397/1/012082

Zhou, S., Dong, Z., Wang, H. H., & Chiu, M. M. (2025). A meta-analysis of STEM integration on student academic achievement. Research in Science Education, 55(5), 1273–1302.

Zulfawati, Z., Mayasari, T., & Handhika, J. (2022). The effectiveness of the problem-based learning model integrated STEM approach in improving the critical thinking skills. Jurnal Penelitian Fisika Dan Aplikasinya (JPFA), 12(1), 76–91.