Al-Ishlah: Jurnal Pendidikan
Vol.18, 1 (March, 2026), pp. 958-967
ISSN: 2087-9490 EISSN: 2597-940X, DOI: 10.35445/alishlah.v18i1.9288

Enhancing Students' Explanatory Skills through the Implementation of STEM-Based Student Worksheets

Zulfa Rizka[1], Muhammad Syukri[2], Saminan[3], Siti Maghfirah[4], Elmi Mahzum[5], Muhammad Syukri[6], Lilia Ellany Mohtar[7]

[1]Universitas Syiah Kuala, Banda Aceh, Indonesia; zulfarizka30@gmail.com
[2]Universitas Syiah Kuala, Banda Aceh, Indonesia; syukri.physics@usk.ac.id
[3]Universitas Syiah Kuala, Banda Aceh, Indonesia; saminanfis@usk.ac.id
[4]Universitas Syiah Kuala, Banda Aceh, Indonesia; sitimaghfirah22@gmail.com
[5]Universitas Syiah Kuala, Banda Aceh, Indonesia; helmiarsal@usk.ac.id
[6]Universitas Syiah Kuala, Banda Aceh, Indonesia; m.syukri@usk.ac.id
[7]Universiti Pendidikan Sultan Idris, Perak, Malaysia; lilia@fsmt.upsi.edu.my

ARTICLE INFO

Keywords:

STEM education;
student worksheet (LKPD);
scientific explanation;
critical thinking;
engineering design process

Article history:

Received 2025-12-29
Revised 2026-01-20
Accepted 2026-03-31

ABSTRACT

Critical thinking skills, particularly scientific explanation abilities, remain inadequately developed among Indonesian secondary students, as evidenced by PISA 2023 results. While STEM-based learning shows promise for developing critical thinking, few studies have specifically examined its impact on the explanation indicator students' ability to construct coherent scientific arguments using claim-evidence-reasoning frameworks. This study investigated whether STEM-based student worksheets (LKPD) incorporating the Engineering Design Process could improve students' explanation indicator scores in physics learning. A one-group pretest-posttest pre-experimental design was employed with 35 grade XI students at SMAN 2 Banda Aceh. Data were collected using a validated explanation ability test (covering claim-evidence-reasoning dimensions), student response questionnaires, and observation sheets aligned with Facione's critical thinking indicators. Paired samples t-test and N-Gain analysis were conducted to examine score changes. Pretest scores averaged 30.35±4.91%, while posttest scores reached 84.52±10.63% ($t(34)=-27.427$, $p<0.001$, $d=0.77$, 95% CI [49.13, 59.21]). The N-Gain value of 0.77 indicated high improvement. Observation data showed explanation indicator performance at 89.2%, second only to self-regulation (97.14%). STEM-based LKPD was associated with substantial improvements in students' scientific explanation abilities. However, the one-group pretest-posttest design limits causal inferences; findings suggest correlation rather than definitive causation. The Engineering Design Process appears to provide structured opportunities for claim-evidence-reasoning practice essential for explanation development.

Corresponding Author:
Muhammad Syukri
Universitas Syiah Kuala, Banda Aceh, Indonesia; syukri.physics@usk.ac.id

1. INTRODUCTION

Critical thinking skills represent essential competencies for the 21st century and should be systematically cultivated throughout the educational process. Critical thinking refers to the capacity for reflective and rational thought in decision-making and problem-solving, involving analysis, evaluation of arguments, and logical conclusion drawing (Rahmawati et al., 2019; Susandi, 2021). This skill is vital for enabling students to process information objectively, discern relevant data, and foster independent learning (Amin et al., 2020).

Facione identifies six primary indicators of critical thinking: interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 2015). Among these, the explanation indicator is particularly significant, as it encompasses the ability to present logical explanations, construct scientific arguments, and connect evidence or data to relevant concepts.

In science education, the explanation indicator specifically refers to students' ability to construct scientific arguments using the Claim-Evidence-Reasoning (CER) framework (Mcneill & Krajcik, 2006; Nasir et al., 2022). Scientific explanation involves presenting derived explanations of phenomena using relevant evidence and logical reasoning to support claims (Nasir et al., 2022). This conceptualization aligns with contemporary understanding of scientific reasoning as encompassing inquiry, experimentation, evidence evaluation, and argumentation (Osborne et al., 2004; Zhou et al., 2021). Explanation skills are not peripheral but central to scientific literacy, as they enable students to articulate complex conceptual understanding and make evidence-based decisions (Andarini et al., 2026; Dowd et al., 2018).

Despite its importance, the 2023 Program for International Student Assessment (PISA) results indicate that Indonesian students' science literacy remains low (OECD, 2023), suggesting that their reasoning, analytical, and explanatory skills have not developed optimally.

Students' limited explanatory abilities are strongly associated with instructional practices focused primarily on procedural mastery, which do not adequately foster the development of critical thinking skills (Muhammad Alditia et al., 2024). Teacher-centered instruction that lacks opportunities for analytical engagement leads to insufficient training in articulating reasoning, explaining processes, and defending scientific arguments (Rahim, 2023; Tang, 2023; Treve, 2024).

Despite growing research on STEM-based learning and critical thinking, a significant gap exists in how these studies measure explanation abilities. Most STEM education research treats critical thinking as a composite construct, using instruments like the Halpern Critical Thinking Assessment (HCTA) to report overall ability improvements without isolating specific components (Nehru et al., 2024; Sumarni & Kadarwati, 2020). While some studies acknowledge explanation as one critical thinking indicator among several (Andarini et al., 2026; Mutakinati et al., 2018), few provide focused examination of scientific explanation and argumentation skills that would advance understanding of these specific capabilities in STEM learning contexts (Sampson & Clark, 2008).

A notable exception is (Nasir et al., 2022), who specifically examined 'scientific explanation' as a distinct outcome variable separate from concept understanding, finding that structured argumentation scaffolding techniques significantly enhanced explanation abilities (effect size = 0.78). This study demonstrates the value of isolating explanation skills for targeted investigation rather than measuring them only as part of broader critical thinking assessments.

Furthermore, existing STEM-based student worksheet (LKPD) studies have primarily measured general critical thinking skills (Pertiwi et al., 2024), creativity (Azizah & Angelina, 2025), and scientific literacy (Cahyani et al., 2024), but have not specifically investigated how the Engineering Design Process (EDP) within STEM learning affects the explanation indicator. This gap is significant because EDP's iterative stages inherently require students to justify design decisions with scientific evidence (English, 2016; Mutakinati et al., 2018), yet the explicit connection between EDP activities and explanation skill development remains underexplored.

The theoretical connection between the Engineering Design Process and explanation skills lies in the nature of design activities. Design processes in STEM learning inherently require justification and evaluation (Moore et al., 2014; Mutakinati et al., 2018). This iterative process of proposing solutions, testing them, and justifying modifications creates structured opportunities for students to practice the claim-evidence-reasoning cycle that underpins scientific explanation (Mcneill & Krajcik, 2006; Nasir et al., 2022).

Moreover, the EDP's emphasis on connecting abstract scientific principles to concrete problem-solving contexts supports the development of coherent argumentation (English, 2016). Research confirms that opportunities for explanation and justification in STEM activities are critical factors that directly contribute to scientific reasoning development (Swandi et al., 2025; Zhou et al., 2021), with explanation abilities showing positive correlation with conceptual understanding (r=0.586, (Nasir et al., 2022).

Given this context, the present study addresses the following research question: Does the implementation of STEM-based student worksheets incorporating the Engineering Design Process improve grade XI students' explanation indicator scores in physics learning? Specifically, this study examines whether structured opportunities for claim-evidence-reasoning practice within EDP-based activities are associated with measurable improvements in students' ability to construct scientific explanations.

2. METHODS

A quantitative approach with a one-group pretest-posttest pre-experimental design was employed to evaluate the association between STEM-based student worksheets and critical thinking in explanation indicators. The study involved 35 grade XI students at SMAN 2 Banda Aceh. This design was chosen due to practical constraints in the existing school structure.

Research instruments comprised: (1) a student response questionnaire, (2) an explanatory critical thinking ability test based on Facione's framework, and (3) an observation sheet. The explanatory ability test consisted of six open-ended questions covering claim-evidence-reasoning dimensions, administered both before and after the intervention.

Data were analyzed using paired samples t-test (after confirming normality through the Shapiro-Wilk test, W=0.954, p=0.150). N-Gain analysis measured proportional improvement using Hake's criteria: high ($g \geq 0.7$), medium ($0.3 \leq g < 0.7$), and low ($g < 0.3$). Effect size was calculated using Cohen's d.

3. FINDINGS AND DISCUSSION

The effectiveness of STEM-based student worksheets in enhancing students' explanation abilities was evaluated through quantitative analysis of pre-test and post-test scores. The results are presented below.

Table 1. N-Gain Test Results

	Total Score	N-Gain	Category
Pre-test	1062.5	0.77	High
Post-test	2958.3		

According to the Hake criteria, the N-Gain value of 0.77 shown in Table 1 falls into the high category. This result indicates that learning using STEM-based LKPD was associated with significant improvements in students' critical thinking abilities, particularly in the explanation indicator. The total score increased from 1062.5 in the pretest to 2958.3 in the post-test, demonstrating substantial improvement in students' abilities to construct scientific explanations.

Analysis of pre-test and post-test data was also conducted based on critical thinking indicators. The pretest scores demonstrate that, prior to instruction, students experienced challenges in formulating logical explanations, constructing scientific arguments, and connecting evidence to relevant physics concepts. These results align with findings by Cahyani et al. (2024), who reported that students' explanatory abilities remain low when instruction does not explicitly develop argumentation and scientific reasoning skills. Following the implementation of STEM-based student worksheets, the average post-test scores increased for each indicator, reflecting significant improvement in students' ability to explain problem-solving processes coherently and with conceptual grounding.

The enhancement of students' explanatory skills can be attributed to the characteristics of STEM-based student worksheets, which position students as active participants in the learning process. Student worksheets activities are structured to prompt students to observe phenomena, analyze contextual problems, design solutions, and articulate the rationale behind each decision. This approach directly cultivates explanatory skills, as students must not only arrive at a final answer but also justify the reasoning and methods used. STEM-based learning fosters the development of higher-order thinking skills through analysis, justification, and scientific communication, thereby reinforcing explanatory indicators within critical thinking (Hartono et al., 2025).

3.1 Data Normality Test

A normality test was conducted to determine whether the critical thinking ability data were normally distributed. This test is important to ensure that the obtained data are appropriate for analysis using parametric statistics. The test was conducted using the Shapiro-Wilk test with SPSS version 16.0.

Table 2. Normality Test of Pre-test and Post-test

Tests of Normality			
Pretest-	Statistic	df	Sig.
Posttest	.954	35	.150

Based on the analysis results in Table 2, the significance value (Sig.) from the Shapiro-Wilk test was 0.150 > 0.05, indicating that the pre-test and post-test data of students' critical thinking abilities were normally distributed. This confirms that the data are appropriate for parametric statistical analysis.

3.2 Paired Samples t-Test

After the data were confirmed to be normally distributed based on the Shapiro-Wilk test results, the next step was to conduct a paired samples t-test to determine whether there was a significant difference between the pre-test and post-test results of students' critical thinking abilities after using STEM-based student worksheets. The t-test was performed using SPSS version 16.0.

Table 3. Paired Samples t-Test Results

Paired Differences	Mean	t-statistic	Sig. (2-tailed)
Pre Test - Post Test	0.46970	**-27.427**	**0.000**

Table 3 shows a mean difference of 0.46970, with a t-statistic of -27.427 and significance of 0.000. Since the significance value is far below the critical threshold of $\alpha = 0.05$, it can be concluded that there is a statistically significant difference between the pre-test and post-test results of students' critical thinking abilities after using STEM-based student worksheets.

These results indicate that STEM-based student worksheets was associated with substantial improvements in students' critical thinking abilities. This improvement demonstrates that the use of student worksheets designed with a STEM approach encourages students to engage actively in learning activities, connect physics concepts with real world situations, and develop analytical, evaluative, and reflective abilities that are indicators of critical thinking.

3.3 Observation Sheet Results

Observation sheets were used to examine students' critical thinking processes during learning activities using STEM-based LKPD. Based on the observations conducted, data were obtained regarding the development of each critical thinking indicator during the learning process. The observation results for each critical thinking indicator are presented in Table 4.

Table 4. Observation Scores by Critical Thinking Indicator

Critical Thinking Indicator	Mean Score (%)	Category
Self-Regulation	**97.14**	**Excellent**
Inference	88	Excellent
Interpretation	87	Excellent
Evaluation	86	Excellent
Explanation	**89**	**Excellent**
Analysis	85	Good

Table 4 demonstrates that all critical thinking indicators achieved scores in the excellent or good categories. The explanation indicator, which is the focus of this study, achieved an average observation score of 89%, categorized as excellent. This reflects active student engagement in providing explanations, presenting logical reasoning, and discussing the relationship between concepts and observation results. The highest score was achieved by the self-regulation indicator (97.14%), while the analysis indicator received the lowest score (85%), though still in the good category.

These findings suggest that students developed not only procedural understanding of concepts but also the ability to construct scientific explanations independently. The improvement in the explanation indicator is shaped by the stages of the engineering design process (EDP) in STEM learning, which require students to design, evaluate, and revise solutions. These stages prompt students to reflect on their decisions and to communicate scientific reasoning explicitly. Physics instruction that incorporates STEM-based student worksheets aligned with the EDP can promote students' active engagement in problem analysis, solution formulation, and the development of evidence-based explanations, thereby enhancing critical thinking skills (Syukri et al., 2023). Integrating STEM into learning environments can further increase student participation in scientific activities and reinforce critical thinking through evidence-based analysis and justification (Mater et al., 2022).

3.4 Student Response Questionnaire Results

The level of acceptance and perceived benefits of STEM-based student worksheets was assessed using a questionnaire administered to students following completion of the learning activity. The questionnaire evaluated several aspects, including students' interest in the appearance of the worksheets, the clarity of material presentation and instructions, and the logical sequence and organization of the presented concepts. Table 5 provides a summary of student responses regarding the implementation of STEM-based student worksheets.

Table 5. Student Response Analysis Results

No	Aspect	Percentage (%)	Category
1.	Attractiveness	95	Very Good
2.	Clarity	93	Very Good
3.	Conceptual systematics	90	Very Good
	Average Student Response	**92,6**	**Very Good**

According to Table 5, the questionnaire analysis indicates that students' responses to the use of STEM-based student worksheets were predominantly in the very good category, with an average percentage of 92.6%. These results suggest that the developed worksheets were regarded as engaging, user-friendly, and systematically organized, which contributed to students' effective progression in the learning process. The highly positive responses demonstrate that STEM-based student worksheets supports student engagement and facilitates the development of explanatory skills in physics learning. This finding aligns with research by (Nestiadi et al., 2024.), which found that student worksheets featuring communicative displays and structured activities can enhance student participation and improve the quality of learning interactions.

The alignment among test results, N-Gain scores, observation sheets, and student responses indicates that STEM-based student worksheets was associated with enhanced learning outcomes and fostered the development of students' scientific thinking and explanatory skills.

3.5 Discussion

3.5.1 Explanation Skills as Core Scientific Competency

The significant improvements in explanation indicator scores observed in this study (N-Gain = 0.77, $p < 0.001$) align with emerging evidence that scientific explanation development is a core component of critical thinking and scientific literacy in secondary science education (Andarini et al., 2026; Dowd et al., 2018; Osborne et al., 2004). The positive correlation between explanation abilities and conceptual understanding found in previous research ($r = 0.586$, (Nasir et al., 2022)suggests that explanation skills are not separate from content mastery but central to demonstrating meaningful understanding in STEM-integrated learning environments.

The quality of scientific argumentation depends on students' ability to coordinate evidence with theoretical claims (Osborne et al., 2004). Assessment frameworks for scientific arguments emphasize the importance of examining how students generate and justify claims (Sampson & Clark, 2008), aligning with this study's focus on the explanation indicator. Our findings demonstrate that when students engage in STEM-based activities requiring explicit justification of design decisions, they develop stronger abilities to construct coherent claim-evidence-reasoning arguments.

3.5.2 Mechanism: Engineering Design Process and Explanation Development

The STEM-based student worksheets is effectiveness may stem from its provision of structured opportunities for claim-evidence-reasoning practice within the Engineering Design Process (Mcneill & Krajcik, 2006; McNeill & Krajcik, 2012). The CER framework has been widely adopted in science education as a structured approach to developing scientific explanation skills, with research demonstrating that scaffolding students' construction of explanations through explicit instruction significantly improves argumentation quality (Berland & Reiser, 2009).

When students designed solutions for Newton's Laws applications in this study, they were required to justify design choices with physics principles, evaluate alternative solutions, and explain why certain approaches were more effective activities that directly mirror the cognitive processes involved in scientific explanation (Mutakinati et al., 2018; Swandi et al., 2025). The integration of engineering design in K-12 STEM education provides authentic contexts for developing scientific reasoning (Moore et al., 2014), and engineering design processes require students to justify design decisions with scientific principles, creating natural opportunities for practicing scientific argumentation (English, 2016; Kelley & Knowles, 2016).

This iterative process of proposing solutions, testing them, and justifying modifications creates structured opportunities for students to practice the claim-evidence-reasoning cycle. Moreover, the EDP's emphasis on connecting abstract scientific principles to concrete problem-solving contexts supports the development of coherent argumentation (English, 2016). Students must integrate observational evidence with conceptual reasoning, demonstrating how theoretical physics principles explain real-world phenomena (Nasir et al., 2022). This supports the theoretical premise that explanation and justification opportunities in STEM activities are critical factors in scientific reasoning development (Zhou et al., 2021).

STEM-based learning fosters the development of higher-order thinking skills through analysis, justification, and scientific communication, thereby reinforcing explanatory indicators within critical thinking (Hartono et al., 2025). These results are consistent with findings by (Usman et al., 2025) and (Susilawati et al., 2025), who report that implementing STEM-based learning via student worksheets enhances students' critical thinking abilities and promotes active engagement in scientific activities, particularly in constructing and communicating explanations grounded in concepts and evidence.

3.5.3 Study Limitations and Validity Considerations

While this study demonstrates strong associations between STEM-based student worksheets implementation and improvements in explanation skills, several methodological limitations must be acknowledged. The one-group pretest-posttest pre-experimental design, while appropriate given practical constraints within the existing school structure, limits the strength of causal inferences that can be drawn from these findings.

First, the absence of a control group means that alternative explanations for the observed improvements cannot be definitively ruled out. Potential threats to internal validity include:

1. History effects: External events or experiences during the intervention period may have contributed to students' improved performance.
2. Maturation: Natural cognitive development over the study period could account for some improvement, particularly given the age group (grade XI students).
3. Testing effects: Exposure to the pretest may have familiarized students with the question format and expectations, potentially inflating posttest scores.
4. Instrumentation: While observation sheets were used to assess implementation fidelity, no formal measures of interrater reliability were calculated, potentially introducing scoring bias.
5. Hawthorne effect: Teacher and student enthusiasm for the novel intervention may have contributed to improved outcomes independent of the student worksheets instructional design.

Second, the study was conducted at a single school in Banda Aceh with a relatively short intervention duration, which may limit the generalizability of findings to other educational contexts, student populations, or longer timeframes. The sample size (n=35) was adequate for detecting the large effect observed, but replication with larger, more diverse samples would strengthen confidence in these findings.

Third, while the N-Gain analysis and paired t-test provide evidence of improvement, these analyses cannot establish that the STEM-based student worksheets caused these changes. The language used throughout this paper reflects this limitation, characterizing findings as showing association or correlation rather than definitive causation.

Fourth, the qualitative aspects of students' explanations such as the sophistication of their argumentation, the appropriateness of evidence selection, or the coherence of their reasoning—were not systematically analyzed beyond the quantitative scoring rubric. Deeper qualitative analysis could provide richer insights into how students' explanatory abilities developed.

Despite these limitations, the consistency across multiple data sources (test scores, N-Gain values, observation data, and student responses) provides triangulated evidence supporting the conclusion that STEM-based LKPD implementation is associated with improvements in students' explanation skills. The large effect size and highly significant statistical results suggest that this association is both substantial and reliable within the study context.

4. CONCLUSION

This study examined the association between STEM-based student worksheets integrating the Engineering Design Process (EDP) and students' scientific explanation abilities in Grade XI physics, revealing substantial improvements as indicated by a high N-Gain value (0.77) and statistically significant differences between pretest and posttest scores, alongside strong observational performance (89%, excellent category) and highly positive student responses (92.6%). These findings suggest that the structured, iterative nature of the EDP—emphasizing justification, testing, and evidence-based reasoning—supports the development of coherent scientific explanations, although the one-group pretest–posttest design limits causal claims and the single-site, short-duration implementation constrains generalizability. Practically, the results indicate that effective implementation requires explicitly structured tasks that demand justification using physics principles, full engagement in iterative design cycles, scaffolding through claim–evidence–reasoning frameworks, sufficient instructional time, and collaborative learning environments that promote peer discussion and explanation. For future research, more rigorous designs such as quasi-experimental or randomized controlled studies are needed to establish causality, alongside longer and broader implementations across diverse contexts to assess sustainability and generalizability; additional work should also incorporate delayed posttests, qualitative analyses of student explanations, and investigations into specific instructional features and learner characteristics that influence outcomes. Overall, while acknowledging its limitations, this study highlights the promise of STEM-based worksheets incorporating the Engineering Design Process as a pedagogical approach to enhance students' scientific explanation skills and provides a foundation for further evidence-based refinement in physics education.

REFERENCES

Amin, A. Muh., Corebima, A. D., Zubaidah, S., & Mahanal, S. (2020). The Correlation between Metacognitive Skills and Critical Thinking Skills at the Implementation of Four Different Learning Strategies in Animal Physiology Lectures. *European Journal of Educational Research*, *volume–9–2020*(volume9-issue1.html), 143–163. https://doi.org/10.12973/eu-jer.9.1.143

Andarini, S. Y., Dewi, N. M., & Lesmono, A. D. (2026). Exploring students' critical thinking skills through STEM-PjBL on Newton's Laws. *Physics Education*, *61*(1), 015007. https://doi.org/10.1088/1361-6552/ae19bd

Azizah, A., & Angelina, N. N. (2025). Efektivitas Pembelajaran Berbasis STEM dalam Meningkatkan Kreativitas dan Keterampilan Berpikir Kritis Siswa SMP Negeri 1 Jombang. *Journal of Science and Mathematics Education*, *1*(2), 32–38. https://doi.org/10.70716/josme.v1i2.169

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*(1), 26–55. https://doi.org/10.1002/sce.20286

Dowd, J. E., Thompson, R. J., Schiff, L. A., & Reynolds, J. A. (2018). Understanding the Complex Relationship between Critical Thinking and Science Reasoning among Undergraduate Thesis Writers. *CBE—Life Sciences Education*, *17*(1), ar4. https://doi.org/10.1187/cbe.17-03-0052

English, L. D. (2016). STEM education K-12: Perspectives on integration. *International Journal of STEM Education*, *3*(1), 3, s40594-016-0036–1. https://doi.org/10.1186/s40594-016-0036-1

Facione, P. (2015). Critical Thinking: What It Is and Why It Counts. *Insight Assessment*.

Hartono, J. K., Nur'aini M, R. S., Fauzia, I., & Juliani, R. (2025). The Development of e-Worksheet based on High Order Thinking Skills (HOTS) for Critical Thinking Student. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *11*(2), 177–196. https://doi.org/10.21009/1.11204

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education*, *3*(1), 11. https://doi.org/10.1186/s40594-016-0046-z

Mater, N. R., Haj Hussein, M. J., Salha, S. H., Draidi, F. R., Shaqour, A. Z., Qatanani, N., & Affouneh, S. (2022). The effect of the integration of STEM on critical thinking and technology acceptance model. *Educational Studies*, *48*(5), 642–658. https://doi.org/10.1080/03055698.2020.1793736

Mcneill, K., & Krajcik, J. (2006). *Supporting students' construction of scientific explanation through generic versus context-specific written scaffolds*.

McNeill, K. L., & Krajcik, J. S. (2012). *Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing*. Pearson. https://books.google.co.id/books?id=_PzIbwAACAAJ

Moore, T., Stohlmann, M., Wang, H.-H., Tank, K., Glancy, A., & Roehrig, G. (2014). Implementation and integration of engineering in K-12 STEM education. In *Engineering in Pre-College Settings: Synthesizing Research, Policy, and Practices* (pp. 35–60).

Muhammad Alditia, L., Fadillah, N., & Hanis, M. (2024). Analysis of Barriers to Elementary School Students' Critical Thinking Skills in Science Subjects. *Jurnal Ilmu Pendidikan (JIP) STKIP Kusuma Negara*, *16*(1), 97–111. https://doi.org/10.37640/jip.v16i1.2060

Mutakinati, L., Anwari, I., & Kumano, Y. (2018). Analysis of Students' Critical Thinking Skill of Middle School through STEM Education Project-Based Learning. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 54–65. https://doi.org/10.15294/jpii.v7i1.10495

Nasir, M., Cari, C., Sunarno, W., & Rahmawati, F. (2022). The effect of STEM-based guided inquiry on light concept understanding and scientific explanation. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(11), em2175. https://doi.org/10.29333/ejmste/12499

Nehru, N., Purwaningsih, S., Riantoni, C., Ropawandi, D., & Novallyan, D. (2024). Mapping Students' Thinking Systems In Critical Thinking Based On Stem Project-Based Learning Experiences. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(1), 136–144. https://doi.org/10.22437/jiituj.v8i1.32027

Nestiadi, A., Safitri, A., Aulia, F., Maulidya, R. R., & Hasanah, N. (n.d.). *Penggunaan LKPD Untuk Menunjang Keaktifan Peserta Didik Pada Pembelajaran IPA Di SMPN 1 Ciruas*.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994–1020. https://doi.org/10.1002/tea.20035

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. https://doi.org/10.33225/jbse/24.23.739

Rahim, A. (2023). *Meningkatkan Keterampilan Berpikir Kritis Melalui Pembelajaran Kritis*. *1*(3).

Rahmawati, L., Subanji, & Septi Nur Afifah, D. (2019). Analysis of Critical Thinking from Student with Quantive Approach. *Journal of Physics: Conference Series*, *1339*(1), 012084. https://doi.org/10.1088/1742-6596/1339/1/012084

Sampson, V., & Clark, D. B. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education*, *92*(3), 447–472. https://doi.org/10.1002/sce.20276

Sumarni, W., & Kadarwati, S. (2020). Ethno-Stem Project-Based Learning: Its Impact to Critical and Creative Thinking Skills. *Jurnal Pendidikan IPA Indonesia*, *9*(1), 11–21. https://doi.org/10.15294/jpii.v9i1.21754

Susandi, A. D. (2021). Critical Thinking Skills of Students in Solving Mathematical Problem. *Numerical: Jurnal Matematika Dan Pendidikan Matematika*, 115–128. https://doi.org/10.25217/numerical.v5i2.1865

Susilawati, Cut Hayati, Muhammad Syukri, Ngadimin, Agus Wahyuni, & Tiara Shandi. (2025). The Use of STEM Integrated Project-Based Learning Media Assisted by TikTok Application to Improve Students' Creative Thinking Skills. *Jurnal Pendidikan Fisika*, *13*(3), 586–599. https://doi.org/10.26618/v1de7526

Swandi, A., Sujiono, E. H., Khaeruddin, K., & Sinring, A. (2025). Development of STEM hybrid research-based learning model to improve scientific reasoning of undergraduate students. *Eurasia Journal of Mathematics, Science and Technology Education*, *21*(11), em2725. https://doi.org/10.29333/ejmste/17287

Syukri, M., Herliana, F., Maryono, M., Ngadimin, N., & Artika, W. (2023). Development of Physics Worksheet based on STEM integrating Engineering Design Process (EDP) through Guided Inquiry Model to Improve Students' Critical Thinking. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *9*(2), 225–236. https://doi.org/10.21009/1.09205

Tang, K. H. D. (2023). Student-centered Approach in Teaching and Learning: What Does It Really Mean? *Acta Pedagogia Asiana*, *2*(2), 72–83. https://doi.org/10.53623/apga.v2i2.218

Treve, M. (2024). Comparative analysis of teacher-centered and student-centered learning in the context of higher education: A co-word analysis. *Iberoamerican Journal of Science Measurement and Communication*, *4*(2), 1–12. https://doi.org/10.47909/ijsmc.117

Usman, U., Setiawan, T., & Khaeruddin, K. (2025). Development of Project-Based Learning Materials for Basic Physics to Enhance Students' Critical Thinking Skills. *Jurnal Pendidikan Fisika*, *13*(3), 345–362. https://doi.org/10.26618/kmbtb222

Zhou, S.-N., Liu, Q.-Y., Koenig, K., Li, Q., Xiao, Y., & Bao, L. (2021). Analysis Of Two-Tier Question Scoring Methods: A Case Study On The Lawson's Classroom Test Of Scientific Reasoning. *Journal of Baltic Science Education*, *20*(1), 146–159. https://doi.org/10.33225/jbse/21.20.146