Berkala Ilmiah Pendidikan Fisika
https://ppjp.ulm.ac.id/journal/index.php/bipf
e-ISSN: 2549-2764 p-ISSN: 2337-604X
Vol 13 No 1 2025
DOI: 10.20527/bipf.v13i1.20182

Critical Thinking Ability in a STEM-Based Problem-Based Learning Model: A Focus on Temperature and Heat

Aprilita Ekasari* and Algiranto
Physics Education, Faculty of Teacher Training and Education
Universitas Musamus Merauke, Merauke, Indonesia
aprilita@unmus.ac.id

Article Info

Article history:
Received: August 3, 2024
Revised: October 31, 2024
Accepted: January 23, 2025

Keywords:
Critical thinking skills
Problem-based learning
STEM
Temperature and heat

Abstract

This study explores enhancing students' critical thinking skills by applying a STEM-centered problem-based learning (PBL-STEM) model. It evaluates students' responses to this pedagogical approach. A quasi-experimental design with a static group pretest-posttest framework was employed, involving secondary school students from Merauke City. The instrument used for data collection was a Critical Thinking Ability Test, which included 10 essay questions covering six subtopics related to temperature and heat and incorporated five indicators of critical thinking. The test's reliability, as measured by Cronbach's alpha, was 0.739. Additionally, student responses to the PBL-STEM method were gathered through questionnaires. Data were analyzed both descriptively and inferentially. The results indicated that implementing PBL-STEM was effective, significantly improving students' critical thinking skills, with an N-gain of 0.824, classified as high. Furthermore, the significance test revealed that the enhancement in critical thinking through PBL-STEM was greater than that achieved through traditional PBL methods.

To cite this article: Ekasari, A. & Algiranto, A (2025). Critical thinking ability in a STEM-based problem-based learning model: A focus on temperature and heat. *Berkala Ilmiah Pendidikan Fisika*, *13*(1), 12-21.

INTRODUCTION

Physics is a branch of science that explores natural phenomena and observable behaviors, which humans can understand and apply in daily life (Yovianda et al., 2019). It significantly contributes to the advancement of nations by playing a vital role in driving technological innovation (Shishigu et al., 2018). Physics encourages students to understand, reflect upon, and analyze various phenomena and challenges encountered in daily life (Yovianda et al., 2019). The study of physics requires students to develop critical thinking skills to address complex physical problems. Moreover, students actively apply these critical thinking skills in problem-solving (Serungke et al., 2020).

Critical thinking is a form of higher-order thinking closely linked to problem-solving, creative thinking, and decision-making. This type of thinking is non-algorithmic, often complex, and typically leads to multiple solutions. It involves the application of various criteria and is not straightforward (Serex & Blocher, 2019). Critical thinking involves specific processes like reasoning, prediction, and analysis. Social factors and interactions with teachers, parents, and peers can substantially influence the development of critical thinking skills (Alexander, 2014). Asking questions is fundamental to practicing critical thinking and problem-solving. Critical thinking involves evaluating concepts through logical reasoning and decision-making abilities. This form of thinking is essential for students to address complex problems in physics (Chang & Hwang, 2018; Heflin et al., 2017; Faridi et al., 2021).

Critical thinking and problem-solving are both essential and intellectually demanding skills (Ekasari et al., 2022; Ekasari, 2023; Ekasari et al., 2018, 2024; Ekasari, Algiranto, et al., 2023; Ekasari, Diantoro, et al., 2023; Ekasari & Algiranto, 2024; Henukh et al., 2024; Nursiam et al., 2023). Critical thinking skills are particularly important for metacognitive understanding (Ekasari et al., 2022; Henukh et al., 2024). Thinking is not isolated from the content; instead, it is a means of engaging with and understanding various topics. Critical thinking should be integrated and practiced across all subjects at the school level. Research has shown that specific instructional techniques can significantly enhance critical thinking skills (Serex & Blocher, 2019). Therefore, teaching students how to think critically should be a central priority for teachers.

Student achievement in physics remains low due to the ineffectiveness of current teaching models. Teachers often select inappropriate methods, which hinder students from fully realizing their potential (Paryanto et al., 2020). Using unsuitable instructional models also leads to difficulties in overcoming challenges during learning (Lestari et al., 2021). These challenges in problem-solving during practical activities cause students to rely heavily on teachers and peers for assistance and solutions to the problems they encounter (Paryanto et al., 2020). Improving educational outcomes can be achieved by innovatively applying effective teaching models (Lestari et al., 2021). Appropriate instructional strategies can significantly enhance the quality of education (Yovianda et al., 2019).

Critical thinking skills in Indonesia are still not being optimally developed. This is evident because 78% of Indonesian students can only answer science questions at a low level, primarily involving basic recall or memorization (Galuh Rahayuni, 2016). Historically, physics education in Indonesia has emphasized memorization over formulating scientific questions for investigation, using knowledge to explain natural phenomena, and drawing conclusions based on observed facts (Adiwiguna et al., 2019). Current formal education tends to focus on lower-order thinking skills, such as remembering and understanding, rather than higher-order skills, like analysis and synthesis. This limited focus on critical thinking contributes to the low physics achievement of Indonesian students, which is reflected in their performance compared to students from other countries. The results of the 2015 PISA study showed that Indonesia ranked 61st out of 70 countries in science, with a score of 401, while the average score of other PISA participants was 493 (She et al., 2018).

To address the issues mentioned above, it is essential to implement a teaching model that promotes active learning, providing students with opportunities to engage in the learning process and develop their affective skills (Lufri et al., 2021). Therefore, teachers should adopt an appropriate instructional model that aligns with the scientific approach to encourage student participation and enhance their understanding of the material (Rustana et al., 2021). This is supported by (Yerimadesi et al., 2018), who argue that a teaching model that actively engages students and fosters participation is crucial. Such an approach is known as the Active Learning Model.

An interactive learning model is a pedagogical approach that engages students in active cognitive processes (Laili & Lufri, 2019). Active learning is an educational model that involves students in the learning process to achieve meaningful outcomes (Mufit et al., 2018). It is a pedagogical approach that empowers students to cultivate knowledge independently. By engaging in learning tasks, students can attain comprehension independently (Paryanto et al., 2020). One student-centered pedagogical approach that encourages engagement in experimentation to tackle complex challenges is the Problem-Based Learning (PBL) model (Lestari et al., 2021; Paryanto et al., 2020; Shishigu et al., 2018; Yovianda et al., 2019). Moreover, Problem-Based Learning (PBL) fosters critical observation and the development of students' affective domain as they devise solutions to complex problems (Lufri et al., 2021).

Problem-Based Learning (PBL) is an educational methodology that uses authentic, real-world challenges to engage students. A student-centered approach begins with identifying a genuine societal problem, followed by collaborative efforts to find a viable solution (Parno et al., 2019). In PBL, students acquire knowledge through experiential learning by addressing challenges grounded in real-world scenarios (Parno et al., 2021). In PBL, students acquire knowledge through experiential learning by addressing challenges grounded in real-world scenarios (Ekasari, Aprilita, Diantoro, Markus, Parno, 2022; Ekasari, 2023; Ekasari et al., 2018, 2024; Ekasari, Algiranto, et al., 2023; Ekasari, Diantoro, et al., 2023; Ekasari & Algiranto, 2024; Henukh et al., 2024; Nursiam et al., 2023).

Not all physics learning outcomes can be fully realized through Problem-Based Learning (PBL). Physics education is closely related to technology, which is crucial in many aspects of modern life. Technology supports the advancement of society and drives innovation (Razi & Zhou, 2022). This relationship underscores the need for physics education to be oriented toward Science, Technology, Engineering, and Mathematics (STEM) (Han et al., 2015). STEM encompasses various interrelated disciplines where science, mathematics, technology, and engineering are closely connected (Alfika et al., 2019). Mathematics serves as a tool for processing data in science, while technology and engineering represent the practical applications of scientific knowledge (Faoziyah, 2021). The STEM approach to learning aims to create meaningful educational experiences for students by systematically integrating knowledge, concepts, and skills (Ekasari et al., 2024). STEM education fosters scientific inquiry, where students formulate questions and conduct investigations to inform their understanding before engaging in the engineering design process to solve real-world problems (She et al., 2018). According to the National Research Council, STEM learning allows students to apply science, mathematics, and engineering concepts to solve problems with real-world applications (She et al., 2018).

The STEM methodology integrates components of science, technology, engineering, and mathematics concurrently (Parno et al., 2021), allowing students to apply their knowledge in planning, enrichment, and technology integration endeavors, thereby fostering growth in the affective, cognitive, and psychomotor domains of students (Parno et al., 2019; Ercan et al., 2016; Griese et al., 2015). STEM integration improves the quality of learning (Selcen et al., 2017). It makes the learning context more meaningful (Parno et al., 2021) because student team tasks require students to think critically to discern the optimal solution for resolving real-world challenges (Han et al., 2015). In physics education, STEM facilitates critical thinking (Han et al., 2015) and helps students engage with complex problems in the 21st century (Jamaludin & Hung, 2017). In essence, the STEM approach necessitates that students engage in critical thinking to resolve complex issues, reason logically, explore novel concepts, cultivate learning autonomy, and foster technology proficiency (Parno et al., 2020). Employing the STEM methodology can enhance students' aptitude for critical thinking.

Integrating STEM into Problem-Based Learning (PBL) can enhance students' analytical thinking skills. Therefore, this study aims to implement PBL infused with STEM elements to improve critical thinking by comparing students' academic performance in PBL-STEM courses with those in traditional PBL classes.

METHOD

This study used a quasi-experimental design with a static group pretest-posttest format (Kutlu & Korkmaz, 2013). The study involved 50 eighth-grade students from a secondary education institution in Merauke, Indonesia. The participants were divided into 25 students in the experimental group (PBL-STEM) and 25 in the control group (PBL). Pre-tests and post-tests were administered before and after the intervention to assess students' critical thinking skills. The research instrument was validated, and the reliability of the test, measured by Cronbach's alpha, was 0.739. The indicators of critical thinking skills used in this study were interpretation, analysis, inference, explanation, and self-regulation. After the educational sessions, a survey was distributed to gather feedback from students regarding their experience with PBL-STEM. Table 1 illustrates the differences between the PBL-STEM and PBL instructional methodologies (Parno et al., 2021).

Table 1 Comparison of the learning process between PBL-STEM and PBL

PHASE	STEM-PBL	PBL
I	Orientating students to the problem-asking questions and defining the problem	Orientating students to the problem
II	Organizing students to learn - planning and carrying out investigations	Organizing students to learn
III	Guiding individual or group experience – planning and conducting investigations	Guiding individual or group experience
IV	a. Developing and presenting work - developing and using modeling b. Developing and presenting work using math and computational thinking c. Developing and presenting work - building explanations and designing solutions	Developing and presenting work
V	a. Analyzing and evaluating the procedure - analyzing and interpreting data b. Analyzing and evaluating procedures - engaging in arguments from evidence c. Analyzing and evaluating procedures - acquiring, evaluating, and communicating information	Analyzing and evaluating the procedure

The study instrument was a critical thinking ability test containing 10 essay items, covering six subtopics of temperature and heat (Serway & Jewett, 2014) and assessing five indicators of critical thinking skills (Tiruneh et al., 2017), with a Cronbach's alpha reliability of 0.739. The collected data were analyzed using a normality test (Leech et al., 2005), homogeneity test (Leech et al., 2005), N-gain (Hake, 1998), and t-test (Hake, 1998).

RESULTS AND DISCUSSION

The PBL-STEM learning conducted in this study was carried out offline, focusing on temperature and heat materials. The learning stages followed those outlined in Table 1. The study was conducted over four meetings, each week consisting of two meetings, each allocated 2 lesson hours. The learning process was supported by completing LKPD (*Lembar Kerja Peserta Didik*), projects, and offline learning.

Table 2 Critical thinking ability of students in PBL-STEM and PBL groups

Parameter	PBL-STEM		PBL	
	Pre-test	Post-test	Pre-test	Post-test
Mean value	61	92.60	61	79
Highest score	65	100	65	90
Lowest score	55	80	55	70
Standard deviation	3.535	8.675	3.535	7.071
Variance	12.5	75.25	12.5	50
N-gain	0.824		0.521	

Table 2 indicated that students' critical thinking skills improved more in the PBL-STEM group compared to the PBL group. The PBL-STEM approach was more effective in fostering active learning and student motivation. It helped students actively engage with engineering and scientific principles, allowing them to gain deeper knowledge of science and mathematics. This approach enhanced their skills and ability to apply their learning to real-world situations (Parno et al., 2019). The product design processes empowered students to integrate and articulate their understanding of concepts by applying STEM principles (Parno et al., 2020). As a result, concepts that were typically presented in isolation could be transformed into tangible, real-world experiences. This could inspire students to delve deeper into their learning endeavors (Parno et al., 2019). Additionally, integrating STEM into the educational approach served as a source of inspiration for students' future career aspirations and fostered a heightened enthusiasm for mathematics and science (Parno et al., 2021). Overall, the increased motivation stemming from PBL-STEM education could enhance students' critical thinking ability in their daily lives (Yuliati et al., 2018).

In this study, students in the PBL-STEM class demonstrated superior critical thinking skills compared to those in the PBL class. Integrating STEM in PBL encouraged students to proactively utilize their knowledge to address real-life challenges (Hsiang-Yun Chen et al., 2017). On the other hand, the PBL model held substantial potential to enhance students' attitudes and interest in STEM subjects (Laforce et al., 2017). This led to a boost in student motivation for learning (Parno et al., 2021). Indeed, by implementing the STEM approach, students acquired comprehensive knowledge, developed proficient problem-solving skills, and enhanced their critical thinking abilities (Lafifa et al., 2022).

Table 3 illustrates substantial mean differences in the enhancement of critical thinking skills between students in the PBL-STEM and PBL groups. The normality and homogeneity tests reveal that the critical thinking data for both groups are normally distributed and homogeneous.

Table 3 Results of independent t-test of students' critical thinking abilities in PBL-STEM and PBL classes

Group		Normality Test	Homogeneity Test	Test t
STEM-PBL	Pre-test	0.200	0364	0
	Post-test	0.124		
PBL	Pre-test	0.200		
	Post-test	0.200		

Table 3 unveiled a substantial discrepancy in the mean enhancement of students' critical thinking skills between those in the PBL-STEM cohort and those in the PBL group. Integrating STEM into the PBL learning process could profoundly impact students' analytical thinking abilities. The effectiveness of merging the PBL model with the STEM approach lay in PBL's capacity to enhance students' understanding through the stimuli presented by the STEM methodology (Ariyatun & Octavianelis, 2020; Hasanah et al., 2021; Nurazmi & Bancong, 2021; Octafianellis et al., 2021; Prastika et al., 2022; Putri et al., 2020; Rohmah et al., 2021; Zulfawati et al., 2022). Combining both approaches yielded more effective outcomes, as PBL offered students the chance to assess and enhance their comprehension (Nasution et al., 2018). Furthermore, the STEM methodology was distinguished by its ability to motivate students to recognize real-world problems and develop solutions for these challenges (Wahdaniyah et al., 2023) and provide conclusions that helped build new understanding based on experiences gained during the learning process (Hadi, 2021). Additionally, further studies suggested that the integration of PBL with STEM elicited a positive response from students, making them more amenable to and appreciative of the educational process (Rohmah et al., 2021). From this explanation, it was apparent that integrating PBL with STEM could substantially enhance students' capacity for critical thinking. As a result, this study could serve as a valuable reference for creating educational resources. However, it was imperative to acknowledge that this study was limited to investigating the influence of PBL-STEM integration on critical thinking abilities. Subsequent studies should explore the ramifications of PBL-STEM integration on additional cognitive skills, such as inventive thinking, deliberation, and beyond, to expand the existing scholarly work.

CONCLUSION

Integrating STEM into the learning process enhanced students' critical thinking abilities by providing opportunities to identify and solve real-world problems. PBL characteristics aligned well with STEM, making their combined application more effective in boosting critical thinking abilities. The findings indicated that the PBL-STEM implementation was successful and led to a substantial enhancement in critical thinking skills, with an N-gain of 0.824, categorized as high. The significant test results demonstrated that the improvement in students' critical thinking abilities through PBL-STEM was greater than that through traditional PBL methods.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, AE and A; methodology, AE and A; formal analysis, AE; writing—preparation of the original draft, AE.

REFERENCES

Adiwiguna, P. S., Dantes, N., & Gunamantha, I. M. (2019). The influence of the stem-oriented problem based learning model on the critical thinking ability and scientific literacy of class v elementary school students in gugus i gusti ketut pudja. *Indonesian Journal of Basic Education*, *3*(2), 94–103.

Alexander, P. A. (2014). Thinking critically and analytically about critical-analytic thinking: an introduction. *Educational Psychology Review*, *26*(4), 469–476. https://doi.org/10.1007/s10648-014-9283-1

Alfika, Z. A., Mayasari, T., & Kurniadi, E. (2019). Modul stem berbasis pemecahan masalah dengan tema rumah dome. *Jurnal Pendidikan Fisika*, *7*(1), 93. https://doi.org/10.24127/jpf.v7i1.1566

Ariyatun, A., & Octavianelis, D. F. (2020). Pengaruh model problem based learning terintegrasi stem terhadap kemampuan berpikir kritis siswa. *JEC: Journal of Educational Chemistry*, *2*(1), 33. https://doi.org/10.21580/jec.2020.2.1.5434

Chang, S. C., & Hwang, G. J. (2018). Impacts of an augmented reality-based flipped learning guiding approach on students' scientific project performance and perceptions. *Computers and Education*, *125*, 226–239. https://doi.org/10.1016/j.compedu.2018.06.007

Ekasari, A., Diantoro, M., & Parno, P. (2022). Pembelajaran berbasis masalah mampu meningkatkan kemampuan metakognisi siswa sma. *Journal on Teacher Education*, *4*(2), 1424-1430.

Ekasari, A. (2023). Peningkatan penguasaan konsep dengan menerapkan problem based learning (pbl) berbantuan simulasi phet. *Al Jahiz: Journal of Biology Education Research*, *4*(1), 1-8.

Ekasari, A., & Algiranto, A. (2024). Analisis kemampuan pemecahan masalah model doctor materi kinematika pada mahasiswa. *Journal Tecaher Education*, *5*(4), 34–40.

Ekasari, A., Algiranto, A., & Silubun, H. C. A. (2023). Analisis kesalahan mahasiswa dalam menyelesaikan permasalahan tipe higher order thinking skill (hots) pada mata kuliah fisika modern. *Jurnal Pendidikan Fisika*, *12*, 204–210.

Ekasari, A., Diantoro, M., & . P. (2023). The ability of problem-based learning (pbl) to improve problem-solving skills on heat topic among high school students. *KnE Social Sciences*, *202*, 293–299. https://doi.org/10.18502/kss.v8i10.13454

Ekasari, A., Diantoro, M., & Parno, P. (2018). Peningkatan kemampuan Pemecahan masalah siswa SMAN 1 Gondang pada materi kalor dengan Pembelajaran berbasis masalah. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *3*(1), 588–597.

Ekasari, A., & Yuliatun, T. (2024). Analysis of student's problem-solving abilities as an effort to implement the stem-based microlearning approach. *Jurnal Pendidikan Fisika*, *13*(1), 13-17.

Ercan, S., Bozkurt, A. E., Taştan, B., & Dağ, I. (2016). Integrating GIS into science classes to handle STEM education. *Journal of Turkish Science Education*, *13*(Specialissue), 30–43. https://doi.org/10.12973/tused.10169a

Faoziyah, N. (2021). Kemampuan pemecahan masalah matematis siswa melalui pendekatan stem berbasis pbl. *Pasundan Journal of Mathematics Education : Jurnal Pendidikan Matematika*, *11*(1), 50–64. https://doi.org/10.23969/pjme.v11i1.3942

Faridi, H., Tuli, N., Mantri, A., Singh, G., & Gargrish, S. (2021). A framework utilizing augmented reality to improve critical thinking ability and learning gain of the students in Physics. *Computer Applications in Engineering Education*, *29*(1), 258–273. https://doi.org/10.1002/cae.22342

Galuh, R. (2016). Hubungan keterampilan berpikir kritis dan literasi sains pada pembelajaran ipa terpadu dengan model pbm dan stm. *Jurnal Penelitian Dan Pembelajaran IPA*, *2*(2), 131–146.

Griese, B., Lehmann, M., & Roesken-Winter, B. (2015). Refining questionnaire-based assessment of STEM students' learning strategies. *International Journal of STEM Education*, *2*(1). https://doi.org/10.1186/s40594-015-0025-9

Hadi, F. R. (2021). Efektifitas model pbl terintegrasi stem terhadap kemampuan berpikir kritis matematis siswa kelas v sd. *Jurnal Pendidikan Tambusai*, *5*(3), 6644–6649. https://doi.org/10.31004/jptam.v5i3.2005

Hake, R. R. (1998). Interactive-engagement versus traditional methods : A six-thousand-student survey of mechanics test data for introductory physics courses. *American journal of Physics*, *66*(1), 64-74. https://doi.org/10.1119/1.18809

Han, S., Capraro, R., & Capraro, M. M. (2015). How science, technology, engineering, and mathematics (stem) project-based learning (pbl) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science and Mathematics Education*, *13*(5), 1089–1113. https://doi.org/10.1007/s10763-014-9526-0

Hasanah, Z., Tenri, P. A. U., Safrida, S., Artika, W., & Mudatsir, M. (2021). Implementasi model problem based learning dipadu lkpd berbasis stem untuk meningkatkan keterampilan berpikir kritis pada materi pencemaran lingkungan. *Jurnal Pendidikan Sains Indonesia*, *9*(1), 65–75. https://doi.org/10.24815/jpsi.v9i1.18134

Heflin, H., Shewmaker, J., & Nguyen, J. (2017). Impact of mobile technology on student attitudes, engagement, and learning. *Computers and Education*, *107*, 91–99. https://doi.org/10.1016/j.compedu.2017.01.006

Henukh, A., Astra, I. M., Ekasari, A., & Loupatty, M. (2024). Problem based learning (PBL): Improvment of students' metacognitive abilities. *AIP Conference Proceedings*, *3116*(1). https://doi.org/10.1063/5.0210267

Hsiang-Yun, C., Ching-Kuch. C., & Shi-Jer, L. (2017). A study of high school mathematics teaching method: maker-education combined with mathematical experiments. *US-China Education Review A, 7*(7), 336–347. https://doi.org/10.17265/2161-623x/2017.07.003

Jamaludin, A., & Hung, D. (2017). Problem-solving for STEM learning: navigating games as narrativized problem spaces for 21st century competencies. *Research and Practice in Technology Enhanced Learning*, *12*(1), 1–14. https://doi.org/10.1186/s41039-016-0038-0

Kutlu, M. O., & Korkmaz, Ş. (2013). The teacher attiudes toward the learner control strategy. *Education Sciences*, *8*(2), 225-231.

Lafifa, F., Parno, P., Hamimi, E., & Setiawan, A. M. (2022). Development of stem animation learning media with feedback to facilitate students' critical thinking ability on global warming materials. *Proceedings of the Eighth Southeast Asia Design Research (SEA-DR) & the Second Science, Technology, Education, Arts, Culture, and Humanity (STEACH) International Conference (SEADR-STEACH 2021)*, *627*, 8–15. https://doi.org/10.2991/assehr.k.211229.002

Laforce, M., Noble, E., & Blackwell, C. (2017). Problem-based learning (PBL) and student interest in STEM careers: The roles of motivation and ability beliefs. *Education Sciences*, *7*(4). https://doi.org/10.3390/educsci7040092

Laili, F., & Lufri, L. (2019). The effect of active learning in the form of scientific approach with the use of students worksheet based on problem based learning (pbl) on students' biological knowledge. *Journal of Physics: Conference Series*, *1387*(1). https://doi.org/10.1088/1742-6596/1387/1/012047

Leech, N. L., Barrett, K. C., & Morgan, G. A. (2005). *SPSS for Intermediate Statistics: Use and Interprestation* (Second edi). Lawrence Erlbaum Associates.

Lestari, L., Syafril, S., Latifah, S., Engkizar, E., Damri, D., Asril, Z., & Yaumas, N. E. (2021). Hybrid learning on problem-solving abiities in physics learning: A literature review. *IOP Conference Series: Earth and Environmental Science*, *1796*(1). https://doi.org/10.1088/1742-6596/1796/1/012021

Lufri, L., Laili, F., & Anhar, A. (2021). Effect scientific approach with assistance of student worksheets based pbl towards students' biology affective competence in bacterial learning material. *Journal of Physics: Conference Series*, *1940*(1). https://doi.org/10.1088/1742-6596/1940/1/012119

Mufit, F., Festiyed, F., Fauzan, A., & Lufri, L. (2018). Impact of learning model based on cognitive conflict toward student's conceptual understanding. *IOP Conference Series: Materials Science and Engineering*, *335*(1). https://doi.org/10.1088/1757-899X/335/1/012072

Nasution, M. L., Yerizon, Y., & Gusmiyanti, R. (2018). Students' mathematical problem-solving abilities through the application of learning models problem based learning. *IOP Conference Series: Materials Science and Engineering*, *335*(1). https://doi.org/10.1088/1757-899X/335/1/012117

Nurazmi, N., & Bancong, H. (2021). Integrated stem-problem based learning model: its effect on students' critical thinking. *Kasuari: Physics Education Journal*, *4*(2), 70–77.

Nursiam, N. R., Widodo, W., & Ekasari, A. (2023). PBL : Improving problem solving ability in science subject materials. *Journal On Teacher Education*, *4*(20), 242–250. https://journal.universitaspahlawan.ac.id/index.php/jote/article/view/16261/13492

Octafianellis, D. F., Sudarmin, S., Wijayanti, N., & Panca, H. (2021). Analysis of student's critical thinking skills and creativity after problem-based learning with stem integration. *Journal of Science Education Research Journal*, *2021*(1), 31–37.

Parno, P., Fauziyah, S., Pramono, N. A., Anggraini, R. T., Hidayat, A., Supriana, E., & Ali, M. (2021). The increase of students' critical thinking abilities on optical instrument topic through pbl-stem with virtual simulation media. *Journal of Physics: Conference Series*, *1918*(5). https://doi.org/10.1088/1742-6596/1918/5/052067

Parno, P., Yuliati, L., Ndadari, I. P., & Ali, M. (2020). Project based learning integrated stem to increase students' scientific literacy of fluid statics topic. *Journal of Physics: Conference Series*, *1491*(1). https://doi.org/10.1088/1742-6596/1491/1/012030

Parno, P., Yuliati, L., & Ni'Mah, B. Q. A. (2019). The influence of PBL-STEM on students' problem-solving skills in the topic of optical instruments. *Journal of Physics: Conference Series*, *1171*(1). https://doi.org/10.1088/1742-6596/1171/1/012013

Paryanto, P., Hidayat, F., & Harjanto, C. T. (2020). Implementation of problem based learning to improve student learning achievement in turning machining lesson. *Journal* *of Physics: Conference Series*, *1446*(1). https://doi.org/10.1088/1742-6596/1446/1/012007

Prastika, F. R., Dasna, I. W., & Santoso, A. (2022). Implementation of problem-based learning-stem strategy on students' conceptual understanding and critical thinking in fundamental of chemical equilibrium. *Jurnal Ilmu Pendidikan*, *28*(1), 1. https://doi.org/10.17977/um048v28i1p1-6

Putri, C. D., Pursitasari, I. D., & Rubini, B. (2020). Problem based learning terintegrasi stem di era pandemi covid-19 untuk meningkatkan keterampilan berpikir kritis siswa. *Jurnal IPA & Pembelajaran IPA*, *4*(2), 193–204. https://doi.org/10.24815/jipi.v4i2.17859

Razi, A., & Zhou, G. (2022). STEM, iSTEM, and STEAM: What is next? *International Journal of Technology in Education*, *5*(1), 1–29. https://doi.org/10.46328/ijte.119

Rohmah, H. N., Suherman, A., & Utami, I. S. (2021). Penerapan problem based learning berbasis stem pada materi alat optik untuk meningkatkan kemampuan berpikir kritis peserta didik. *Jurnal Penelitian Pembelajaran Fisika*, *12*(2), 117–123. https://doi.org/10.26877/jp2f.v12i2.7900

Rustana, C. E., Aminah, S., & Budi, A. S. (2021). The development of harmonic oscillation e-module based on problem based learning (pbl) for helping improvement of students' higher order thinking skills (hots). *Journal of Physics: Conference Series*, *1869*(1). https://doi.org/10.1088/1742-6596/1869/1/012174

Selcen, G. S., Harwell, M., Moreno, M., Peralta, Y., & Moore, T. J. (2017). The impact of design-based stem integration curricula on student achievement in engineering, science, and mathematics. *Journal of Science Education and Technology*, *26*(2), 207–222. https://doi.org/10.1007/s10956-016-9673-x

Serex, P., & Blocher, J. D. (2019). Teaching critical thinking and problem solving in a business analysis course. *Operations Management Education Review*, *13*(February), 143–172.

Serungke, M., Muhibbuddin, & Suhrawardi, S. (2020). Implementation of problem-based learning (PBL) with virtual laboratory to improve students' critical thinking and achievement. *Journal of Physics: Conference Series*, *1460*(1). https://doi.org/10.1088/1742-6596/1460/1/012134

Serway, R., & Jewett, J. (2014). *Physics for scientist and engineers with modern physics 9th edition*.

She, H. C., Stacey, K., & Schmidt, W. H. (2018). Science and mathematics literacy: PISA for better school education. *International Journal of Science and Mathematics Education*, *16*. https://doi.org/10.1007/s10763-018-9911-1

Shishigu, A., Hailu, A., & Anibo, Z. (2018). Problem-based learning and conceptual understanding of college female students in physics. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(1), 145–154. https://doi.org/10.12973/ejmste/78035

Tiruneh, D. T., De Cock, M., Weldeslassie, A. G., Elen, J., & Janssen, R. (2017). Measuring critical thinking in physics: Development and validation of a critical thinking test in electricity and magnetism. *International Journal of Science and Mathematics Education*, *15*(4), 663–682. https://doi.org/10.1007/s10763-016-9723-0

Wahdaniyah, N., Agustini, R., & Tukiran, T. (2023). Analysis of effectiveness pbl-stem to improve student's critical thinking skills. *IJORER : International Journal of Recent Educational Research*, *4*(3), 365–382. https://doi.org/10.46245/ijorer.v4i3.312

Yerimadesi, Y., Bayharti, B., Jannah, S. M., Lufri, L., Festiyed, F., & Kiram, Y. (2018). Validity and practitality of acid-base module based on guided discovery learning for senior high school. *IOP Conference Series: Materials Science and Engineering*, *335*(1). https://doi.org/10.1088/1757-899X/335/1/012097

Yovianda, F., Juliani, R., & Amri, H. K. (2019). Application of problem based learning

(PBL) to increasing student activity in the subject matter of temperature and heat. *Journal of Physics: Conference Series*, *1317*(1). https://doi.org/10.1088/1742-6596/1317/1/012157

Yuliati, L., Parno, P., Hapsari, A. A., Nurhidayah, F., & Halim, L. (2018). Building scientific literacy and physics problem solving skills through inquiry-based learning for stem education. *Journal of Physics: Conference Series*, *1108*(1). https://doi.org/10.1088/1742-6596/1108/1/012026

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. https://doi.org/10.26740/jpfa.v12n1.p76-91

AUTHOR PROFILES

Full name: Aprilita Ekasari
Email: aprilita@unmus.ac.id
Affiliation: Physics Education, Faculty of Teacher Training and Education, Universitas Musamus Merauke

Full name: Algiranto
Email: algiranto@unmus.ac.id
Affiliation: Physics Education, Faculty of Teacher Training and Education, Universitas Musamus Merauke