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Effectiveness of Science Technology Engineering Mathematics Problem Based Learning (STEM PBL) and Science Technology Engineering Mathematics Project Based Learning (STEM PjBL) to Improve Critical Thinking Ability

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Abstract: This research sought to compare the effectiveness of Science Technology Engineering Mathematics Problem Based Learning (STEM PBL) and Science Technology Engineering Mathematics Project Based Learning (STEM PjBL) learning models in fostering critical thinking abilities. Quantitative research with a pretest posttest comparison group design is the methodology employed. Based on the outcomes of an investigation of normal and homogeneous data. The increase falls into the high category because the average N-gain value for STEM PjBL on all facets of critical thinking skills is 0.76. STEM PBL, however, is 0.66, thus the growth is in the middle range. The independent t-test results revealed that there was a difference between the two courses in the development of critical thinking abilities, with sig. (2-tailed) of 0.01. The study's findings indicate that both STEM PjBL and STEM PBL can be utilized to enhance critical thinking abilities, but STEM PjBL is more beneficial in this regard.

Keywords: Critical thinking ability; PBL; PjBL; STEM

Introduction

Learning is a relationship between students, and students with teachers in a positive direction. Achieving the goals of learning is influenced by problems in the learning process. Teachers have responsibility for the development of children's souls because they can be called second parents. The learning process is a very important activity, the success of school education depends on the process of learning activities. The role of teachers and students who are directly involved in the learning process typically determines the success of the teaching and learning process. Students and teachers must collaborate when teaching and learning (Fariyani, 2019). Based on the results of observations and interviews with physics teachers and critical thinking skills tests at SMA Negeri 1 Boja, that critical thinking skills are lacking. Where students are less able to respond, ask, analyze, conclude and evaluate questions and problems accompanied by reasons in the learning process. The model used by the teacher is a cooperative model with the lecture method. Based on the interview results that in the lecture method, students become passive, the learning process becomes uninteresting, the teaching process only focuses on understanding words, and it is difficult to control the evaluation of the learning process.

The ability to think is needed by humans to survive, including when humans learn. When learning, individuals will obtain information from sources, then construct it into new knowledge. They will recall and invite previous experiences into the mind and begin to form a chain of associations (Ghanizadeh, 2020). Higher order thinking skills such as critical thinking are frequently incorporated into education (Gunawan et al., 2017). Using the ability to analyze information, express

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opinions with supporting evidence, think broadly, carry out investigations based on new information obtained in thinking is called critical thinking ability (Khoiriyah et al., 2018). Students are taught how to critically investigate, analyze, and evaluate material or viewpoints before deciding whether to accept or reject it (Helmi et al., 2023). The demands of today cannot only be satisfied by cognitive abilities, but also with good skills and attitudes to create a balance between cognitive, psychomotor, and affective (Wahyudi & Winanto, 2018). For students to succeed in school, in life, and in the workplace, critical thinking is crucial. A few key reasons why critical thinking is one of the objectives in education are as follows: (1) Critical thinking can develop if it is frequently trained from learning to thinking in the learning process; (2) Critical thinking skills increase significantly at the high school level; (3) Critical thinking is one of the skills sought after by companies; and (4) Critical thinking is high-level thinking and is one of the important things in making decisions (Cindiati et al., 2021).

Through a variety of scientific procedures or endeavors, the science of physics analyzes natural occurrences. Observations, formulation of issues, creation of hypotheses, execution of experiments, drawing of findings, and discovery of ideas and concepts are some examples of these scientific activities. Additionally, the development of physics is founded on scientific viewpoints that result in theories, concepts, and principles (Trianto, 2017). Understanding rather than memorization, which focuses on the process of forming knowledge through discovery, how to present data mathematically with existing provisions, also in learning it is necessary in physics learning. The purpose of physics learning is that students are able to search, process, construct, and use knowledge (Azizah & Widjajanti, 2019).

Concern over science, technology, engineering, and mathematics (STEM) education has grown globally in the twenty-first century. The term STEM education has been used to refer to activities involving any of the four areas, a STEM related course, or an interconnected or integrated program of study. Definitions of the term have ranged from disciplinary to transdisciplinary approaches (English, 2017). Strimel et al. (2016) noted that technology and engineering are often neglected in secondary-school STEM education, and this neglect perpetuates the educational system's shortcomings in nurturing technology and engineering talent. Due to this issue, Song et al. (2016) and Lin et al. (2021) concurred that planning technology-learning activities (such as hands-on activities that incorporate engineering design) can improve STEM education implementation and give students a thorough cross-disciplinary experience. That is to say, rather than concentrating on learning specific subject matter and ignoring the application of that information, students will have more opportunities to apply STEM knowledge and skill in addressing issues or satisfying demands (K. Y. Lin et al., 2020). STEM, which stands for science, technology, engineering, and mathematics, is a learning approach that concentrates on finding solutions to problems that arise in daily life (Khoiriyah et al., 2018). In order to accomplish learning objectives, the learning model is a crucial component of teaching and learning activities. Teachers use learning models as a reference while preparing lesson plans for the classroom. The learning model is a design that teachers use to conduct learning in class. It is a pattern or design that serves as a guide for learning in class (Ngalimun et al., 2018). One method for enhancing students' critical thinking abilities is the usage of learning models.

One type of learning model is problem based learning (PBL). PBL is a student-centered approach in which students learn by providing solutions to pre-established issues. PBL calls for students to concentrate on challenging issues that lack simple solutions. They work together in groups to determine what they must learn to overcome these challenges (Lei et al., 2016). The A learning strategy that focuses on difficulties from the actual world that are produced in this manner is called problem-based learning (Abdjul et al., 2022; Hermanto et al., 2023; Ntobuo et al., 2023; Payu et al., 2023; Setiawan et al., 2023). Problem-based learning activities or problem based learning is a learning model that can enhance students' critical thinking abilities because it places a focus on providing problems at the beginning of learning, which will stimulate the ability of students who are familiar with problem-solving to think critically (Bashith & Amin, 2017). PBL is a teaching method that exposes real-world issues to motivate pupils to study. The PBL paradigm uses a STEM approach, which combines science, technology, engineering, and mathematics, to teach students while they solve real-world issues (Nurhasnah et al., 2022).

A learning strategy called project based learning (PjBL) makes use of projects or other activities as media. To produce a variety of learning outcomes, learners engage in exploration, assessment, interpretation, synthesis, and information. PjBL is a student-centered learning approach that allows for in-depth topic research. With a research-based approach to challenging, actual, and pertinent topics and concerns, students positively expand their learning. This relates to innovation, the capacity to invent things, use unique development techniques, generate a wide range of creative abilities, or change current objects into new products (Sahida & Zarvianti, 2019). As a viable teaching strategy to encourage learning in its cognitive, social, and emotional components, project-based learning

(PjBL) has gained widespread use in science education. PjBL fosters real practice, deep collaborative multidisciplinary learning, and builds an iterative culture where learners constantly prototype, reflect, redesign, revise, and evaluate, which are considered the core practices of PjBL according to research (Grossman et al., 2019). PjBL fosters students' curiosity and increases their comprehension of fundamental scientific concepts, empowering them to solve issues and become scientifically literate adults (Czerniak, 2018). From the description above, this research aims to see how the effectiveness and differences of STEM PBL and STEM PjBL can improve students' critical thinking skills on light waves material in class XI SMA.

Method

This research was conducted in class XI MIPA SMA N 1 Boja. The obstacles faced by teachers during physics learning based on the results of interviews and initial observations and tests show that students' critical thinking skills are still lacking. A total of 72 students with two class groups, namely experimental class 1 (36 students) and experimental class 2 (36 students) as research subjects. The type of research used is quantitative research with a pretest Posttest comparison group design (Sugiono,2017). In this design there are two experimental classes, and to find out the initial conditions of each group were given a pretest in the form of critical thinking questions. then treatment, namely in experimental class 1 with STEM PjBL and in experimental class 2 with STEM PBL, and a Posttest was conducted to determine the effectiveness and comparison of learning interest of the 2 classes, Table 1 shows the research design.

Table 1. Research Design

Class	Pretest	Treatment	Posttest
experimental 1 (A)	O_{A1}	X_1	O_{A2}
experimental 2 (B)	O_{B1}	X_2	O_{B2}

The research process consists of three stages: planning, implementation, and the end. The planning stage includes making critical thinking skills questions, ATP, teaching modules for the independent curriculum. The implementation stage includes providing treatment, namely STEM PjBL and STEM PBL learning. The final stage includes data analysis, discussion, and conclusion. Data collection instruments are critical thinking questions and learning instruments. The research instruments have been validated by experts and tested for validity. The validity test aims to measure whether the data obtained is valid or not (Sugiyono, 2017). Content validity is determined based on the agreement of experts. Agreement on a subject matter, or often called a measurement domain, determines the level of content validity. The formula proposed by Aiken is shown in equation 1.

$$V = \frac{\Sigma S}{n(c-1)} \quad (1)$$

Prerequisite tests, such as normality (chi square) and homogeneity (F test), were used to examine the pretest and posttest outcomes. The N-Gain test was utilized in the meantime to evaluate how well the learning model improved students' critical thinking abilities. Additionally, an independent t-test was used to compare how well STEM PjBL and STEM PBL improved students' critical thinking abilities.

N-Gain Test

The effectiveness test uses the N-Gain test with the formula shown in equation 2.

$$N\text{-}Gain = \frac{\text{posttest score-pretest score}}{\text{maximum score - pretest score}} \quad (2)$$

The division of the N-gain category can be seen in Table 2.

Table 2. N-Gain Criteria (Hake, 1998)

N-Gain Value	Category
$N \geq 0.7$	High
$0.3 < N < 0.7$	Medium
$N \leq 0.3$	Low

Independent T-Test

With the following criteria for decision-making, the independent t-test test employs the SPSS program: a) If the sig value. (2-tailed) > 0.05, then there is no significant difference. b) If the sig value. (2-tailed) < 0.05, then there is a significant difference (Uyanto, 2019).

Result and Discussion

The results of critical thinking skills are shown in Table 3 and Table 4.

Table 3. Critical Thinking Ability Pre-Test Results

Learning model	Average	Minumum value	Maximun value
STEM PjBL	30	14	46
STEM PBL	32	14	46

Table 4. Critical Thinking Ability Post-Test Results

Learning model	Average	Minumum value	Maximun value
STEM PjBL	83	66	97
STEM PBL	83	58	95

In the scope of education, it is often expressed that the research data of a group of students in a class forms

a normal curve. The assumption of normal data is tested first to prove whether the empric data that has been obtained is in accordance with the normal distribution or not. The normality test needs to be done because data with a normal distribution is one of the requirements that must be met when calculating statistical analysis (Nasrum, 2018).

Table 5. Normality Test Results

	Kind of test	$\mathbf{X^2count}$	Description
STEM PjBL	Pre-Test	2.99	Normal
	Post-Test	10.26	Normal
STEM PBL	Pre-Test	10.27	Normal
	Post-test	6.54	Normal

Tabel 6. Homogeneity Test Results of Class_1 and Class_2

Kind of test	$\mathbf{F_{count}}$	Information
Pre-Test	0.8	Homogeneous
Post-Test	1.07	Homogeneous

The results of the calculation of the chi quadarat normality test in table 3 with X^2table (11.07) and dk (5) show that $X^2count \leq X^2tabel$ so it means that the data is normally distributed. Meanwhile, the homogeneity test is a prerequisite test in statistical analysis that must be proven whether two or more groups of sample data come from populations with the same variance or not (Widana, 2020). A Homogeneity analysis in table 4 using the F test and F_{table} (1.76) btained the value of the results of $F_{count} < F_{table}$ then the data is said to be homogeneous. After that, the N-gain test was conducted for each critical thinking aspect shown in Table 7 and Table 8.

STEM PjBL

The total N-Gain test showed an average N-Gain value of critical thinking ability of 0. 75 with a high category. Meanwhile, the effectiveness of the increase in each critical thinking indicator is shown in Table 7. The results show that there are 4 indicators in the high category and 1 indicator in the medium category. The N-Gain value for each indicator includes the indicator of providing an explanation of 0.72; building basic skills of 0.80; concluding by 0.75; providing further explanation of 0.77. These four indicators have a high level of effectiveness, meaning that students have been able to focus, analyze arguments, ask and answer, are able or have the expertise to adjust to sources, use appropriate procedures, are able to place technology appropriately deconstruct and consider it and define terms appropriately. Meanwhile, the indicator of strategizing and tactics is 0.69; meaning that students are not fully capable of determining actions or making and implementing solutions to problems. The final result of the analysis shows that after students follow the STEM PjBL learning process, students' critical thinking skills improve.

Table 7. N-Gain Test Results of STEM PjBL

Indicator of critical thinking ability	N-Gain	Description
Elementary Clarification	0.72	High
Basic Support	0.80	High
Inference	0.75	High
Advanced Clarification	0.77	High
Strategy and Tactics	0.69	Moderate

Figure. 1 Students' activity in STEM PjBL

There are research pertinent to this research, like as, research with the STEM PjBL Model by Rosyidah et al. (2021) stated that the treatment applied was successful in enhancing students capacity for critical thought. In general, all critical thinking indices increased among students, research by Kurniahtunnisa et al. (2023) showed the STEM PjBL improved students' ability to think critically.

STEM PBL

The total N-Gain test shows the average N-Gain value of critical thinking ability of 0.66 with a moderate category. Meanwhile, the effectiveness of the increase in each critical thinking indicator is shown in Table 8. The results show that there are 4 indicators in the medium category and 1 indicator in the high category. The N-Gain value for each indicator includes the indicator of giving an explanation of 0.67; concluding by 0.60; providing further explanation of 0.66; and developing strategies and tactics of 0.60. These four indicators have a moderate level of effectiveness, meaning that students have not been able to focus, analyze arguments, ask and answer, deduce and consider, define terms appropriately, and have not been able to determine actions or create and implement solutions to problems. Meanwhile, the indicator of building basic skills is 0.71, meaning that students are able or have the expertise to adjust to sources, use appropriate procedures and are able to place technology appropriately. The final result of the analysis shows that after students follow the STEM PBL learning process, students' critical thinking skills improve.

Table 8. N-Gain Test Results of STEM PBL

Indicator of critical thinking ability	N-Gain	Description
Elementary Clarification	0.67	Moderate
Basic Support	0.71	High
Inference	0.60	Moderate
Advanced Clarification	0.66	Moderate
Strategy and Tactics	0.60	Moderate

Figure. 2 Students' activity in STEM PBL

There are research pertinent to this research, like as they stated that students responded favorably to the STEM Problem Based Learning paradigm, which can strengthen critical thinking abilities (Rohmah et al., 2021). Problem-Based Learning (PBL) with a STEM Approach has an effect on critical thinking skills in the E-phase (Putri et al., 2023).

The results of the independent t-test with Sig. (2-tailed) of 0.01, which shows that there is a significant difference in students' critical thinking skills between classes using the STEM PjBL model and classes using the STEM PBL model. The results of the analysis show that the results obtained by the class with the STEM PjBL model are higher than the class using the STEM PBL model. In the STEM PjBL paradigm, students employ every STEM component inherently to support their learning. This type of learning necessitates both individual and group interaction as students use a variety of scientific disciplines-specifically, science, technology, engineering, and mathematics-to jointly solve issues. Each STEM discipline is very beneficial for students' learning (Rismawati et al., 2019). STEM PjBL can be a tool to help pupils develop their critical-thinking skills (Kurniahtunnisa et al., 2023).

According to Rosidin et al. (2018), environmental literacy and student creativity are actualized as challenges and questions are presented, investigations are guided, and dialogues with students are initiated. STEM integrated problem based learning in the learning phase allows for the elaboration, collaboration, and collaborative interaction of students in the problem-analysis process and the reporting process. Students that engage in problem based learning demonstrate a positive outlook, gain interdisciplinary conceptual and procedural knowledge, and demonstrate active behavioral intentions with STEM integration (Lou et al., 2011). Choosing the right learning method can affect student learning outcomes (Ilyas, 2018). In choosing a method, there are several things that must be considered and considered. Among them are the goals to be achieved in learning, the ability and background of students, the ability and background of teachers, the state of the learning process (Safitri et al., 2023). Further research needs to be done to find out what has more influence on critical thinking skills so that the benefits are more optimal. The learning model can be utilized as one of the model options in the learning process based on the research's findings.

Conclusion

Students' critical thinking abilities can be enhanced through STEM PjBL and STEM PBL. STEM PjBL is more effective than STEM PBL in improving students' critical thinking abilities.

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Author Contributions

All authors in this article play an active role, Putri Syntia Monika acts as a writer and researcher who conducts research at the research site. Suharno as the second author played a role in providing input and corrections to the research results, Lita Rahmasari as the third author played a role in assisting in the methodology of the research.

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Conflicts of interest

This study was conducted solely for the purpose of producing scientific writing for the field of education.

References

Abdjul, T., Katili, N., Kurniasari, S., & Yunus, M. (2022). The Effect of the Application of PhET-Assisted Ryleac Model on Students' Science Process Skills. *Jurnal Penelitian Pendidikan IPA*, *8*(5), 2216–2223. https://doi.org/10.29303/jppipa.v8i5.2235

Azizah, I. N., & Widjajanti, D. B. (2019). Keefektifan pembelajaran berbasis proyek ditinjau dari prestasi belajar, kemampuan berpikir kritis, dan kepercayaan diri siswa. *Jurnal Riset Pendidikan Matematika*, *6*(2), 233–243. https://doi.org/10.21831/jrpm.v6i2.15927

Bashith, A., & Amin, S. (2017). The Effect of Problem Based Learning on EFL Students' Critical Thinking Skill and Learning Outcome. *Al-Ta Lim Journal*, *24*(2), 93–102. https://doi.org/10.15548/jt.v24i2.271

Cindiati, M., Claudianingrum, H., Ramadhanty, J. A., Suprapto, P. K., & Diella, D. (2021). The correlation between critical thinking skills and the learning outcomes on musculoskeletal system. *Bioedukasi UNS*, *14*(2), 122–133. Retrieved from https://jurnal.uns.ac.id/bioedukasi/article/download/49911/pdf

English, L. D. (2017). Advancing elementary and middle school STEM education. *International Journal of Science and Mathematics Education*, *15(Suppl 1)*, S5–S24. https://doi.org/10.1007/s10763-017-9802-x

Fariyani, Q. (2019). Model Pembelajaran Kooperatif Jigsaw untuk Meningkatkan Keaktifan dan Hasil Belajar Siswa MTs Kelas VIII. *Jurnal Penelitian Pembelajaran Fisika*, *10*(2), 133–138. https://doi.org/10.26877/jp2f.v10i2.4026

Ghanizadeh, A. (2020). *Higher Order Thinking Skills in the Language Classroom: A Concise Guide*. Cham: Springer.

Grossman, P., Dean, & Kavanagh. (2019). Preparing teachers for project-based teaching. *Phi Delta Kappan*, *100(7),* 43–48. https://doi.org/10.1177/0031721719841338.

Gunawan, Sahidu, H., & Made Yeni Suranti, N. (2017). The Effect of Project Based Learning with Virtual Media Assistance on Student's Creativity in Physics. *Jurnal Ilmiah Pendidikan*. https://doi.org/10.21831/cp.v36i2.13514

Hake, R. (1998). Interactive-Engagement vs. Traditional Methods: A Six-Thousand-Student Survey of Mechanics Test Data for Introductory Physics Courses. *American Journal of Physics*. http://dx.doi.org/10.1119/1.18809

Helmi, M., Asrial, A., & Hariyadi, B. (2023). The Effect of Problem-Based Learning Model on High School Students' Critical Thinking Ability in Biotechnology Viewed from the Level of Confidence. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 6870–6876. https://doi.org/10.29303/jppipa.v9i9.4067

Hermanto, I. M., Nurhayati, Tahir, I., & Yunus, M. (2023). Penerapan Model Guided Context-And Problem-Based Learning Untuk Meningkatkan Pemahaman Konsep Pada Materi Gelombang Bunyi. *JPF (Jurnal Pendidikan Fisika) Universitas Islam Negeri Alauddin Makassar*, *11*(1), 151–162. https://doi.org/10.24252/jpf.v11i1.36233

Ilyas, M. (2018). Pentingnya Metodologi Pembelajaran Bagi Guru. *Al-Aulia: Jurnal Pendidikan dan Ilmu-Ilmu Keislaman*. Retrieved from https://ejournal.stai-tbh.ac.id/al-aulia/article/view/ilyasya

Khoiriyah, N., Abdurrahman, A., & Wahyudi, I. (2018). Implementasi pendekatan pembelajaran STEM untuk meningkatkan kemampuan berpikir kritis siswa SMA pada materi gelombang bunyi. *Jurnal Riset dan Kajian Pendidikan Fisika*, *5*(2), 53–62. https://doi.org/10.12928/jrkpf.v5i2.9977

Kurniahtunnisa, K., Anggraito, Y. U., Ridlo, S., & Harahap, F. (2023). STEM-PjBL Learning: The Impacts on Students' Critical Thinking, Creative Thinking, Communication, and Collaboration Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5007–5015. https://doi.org/10.29303/jppipa.v9i7.2985

Lei, J.-H., Guo, Y.-J., Chen, Z., Qiu, Y.-Y., Gong, G.-Z., & He, Y. (2016). Problem/case-based learning with competition introduced in severe infection education: An exploratory study. *SpringerPlus*, *5*(1), 1821. https://doi.org/10.1186/s40064-016-3532-3

Lin, K. Y., Hsiao, H. S., Williams, P. J., & Chen, Y. H. (2020). Effects of 6E-oriented STEM practical activities in cultivating middle school students' attitudes toward technology and technological inquiry ability. *Research in Science and Technological Education*, *38*(1), 1–18. https://doi.org/10.1080/02635143.2018.1561432

Lin, K.-Y., Wu, Y.-T., Hsu, Y.-T., & Williams, P. J. (2021). Effects of infusing the engineering design process into STEM project-based learning to develop preservice technology teachers' engineering design thinking. *International Journal of STEM Education*, *8*(1), 1. https://doi.org/10.1186/s40594-020-00258-9

Lou, S. J., Liu, Y. H., Shih, R. C., & Tseng, K. H. (2011). The senior high school students' learning behavioral model of STEM in PBL. *International Journal of Technology and Design Education*, *21*(2), 161–183. https://doi.org/10.1007/s10798-010-9112-x

Ngalimun, Fauzani, M., & Salabi, A. (2018). *Strategi dan model pembelajaran*. Banjarmasin: Aswaja Pressindo. Retrieved from https://opac.perpusnas.go.id/DetailOpac.aspx?id=1152879

Ntobuo, N. E., Amali, L. M. K., Paramata, D. D., & Yunus, M. (2023). The Effect of Implementing the Android-Based Jire Collaborative Learning Model on Momentum and Impulse Materials to Improve Student Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *9*(2), 491–497. https://doi.org/10.29303/jppipa.v9i2.2924

Nurhasnah, N., Azhar, M., Yohandri, Y., & Arsih, F. (2022). ETNO-STEM dalam Pembelajaran IPA: A Systematic Literature Review. *Kwangsan: Jurnal*

Teknologi Pendidikan, *10*(2), 147–163. https://doi.org/10.31800/jtp.kw.v10n2.p147--163

Payu, C. S., Pakaya, I., Hermanto, I. M., Irsan, I., & Yunus, M. (2023). Practicality of Guided Inquiry Learning Models Based on Critical Questions (Intersistatic) to Improve Students' Critical Thinking on Temperature and Heat Materials. *Jurnal Ilmiah Profesi Pendidikan*, *8*(1), 11–21. https://doi.org/10.29303/jipp.v8i1.1082

Putri, A. J., Sukmono, T., & Wicaksana, E. J. (2023). The Influence of Problem Based Learning (PBL) Model Based on STEM Approach on Critical Thinking Ability Phase-E in Biology Learning. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 7056–7063. https://doi.org/10.29303/jppipa.v9i9.4568

Rismawati, Sunarno, W., & Sarwanto. (2019). The effect of project based learning on learning environment and learning outcomes in vocational high school students. *Journal of Physics: Conference Series*, *1307*(1), 012010. https://doi.org/10.1088/17426596/1307/1/012010

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

Rosidin, U., W Distrik, I., & Herlina, K. (2018). The Developmment of Assessment Instrument for Learning Science to Improve Student's Critical and Creative Thinking Skills. In *ICEAP Proceeding Book*. Badan Pengembangan dan Pembinaan Bahasa. https://doi.org/10.26499/iceap.v1i1.74

Rosyidah, N. D., Kusairi, S., & Taufiq, A. (2021). Kemampuan Berpikir Kritis Siswa melalui Model STEM PjBL disertai Penilaian Otentik pada Materi Fluida Statis. *Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan*, *5*(10), 1422–1427. https://doi.org/10.17977/jptpp.v5i10.14107

Safitri, R., Hadi, S., & Widiasih, W. (2023). The Effect of the Problem Based Learning Model on the Students Motivation and Learning Outcomes. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 7310–7316. https://doi.org/10.29303/jppipa.v9i9.4772

Sahida, D., & Zarvianti, E. (2019). Development of Problem Based Learning (PBL) practicum guide to improve student Creative Thinking Skills (CTS) in basic physics subject. *Journal of Educational and Learning Studies*, *2*, 39. https://doi.org/10.32698/0492

Setiawan, D. G. E., Arbie, A., Fauzia, A., Buhungo, T. J., Supartin, S., Payu, C. S., & Yunus, M. (2023). The Influence of Inquiry-Based Learning Model on Scientific Literacy in the Rotational Dynamics of a Rigid Bodies. *Jurnal Penelitian Pendidikan IPA*, *9*(3), 1118–1123. https://doi.org/10.29303/jppipa.v9i3.3249

Song, T., Becker, K., Gero, J., DeBerard, S., Lawanto, O., & Reeve, E. (2016). Problem Decomposition and Recomposition in Engineering Design: A Comparison of Design Behavior Between Professional Engineers, Engineering Seniors, and Engineering Freshmen. *Journal of Technology Education*, *27*(1). https://doi.org/10.21061/jte.v27i2.a.3

Strimel, G., & Grubbs, M. E. (2016). Positioning Technology and Engineering Education as a Key Force in STEM Education. *Journal of Technology Education*, *27*(1). https://doi.org/10.21061/jte.v27i2.a.2

Sugiyono. (2017). *Metode penelitian kuantitatif kualitatif dan R&D*.

Trianto. (2017). *Model Pembelajaran Fisika*. Jakarta: Prestasi Pustaka.

Uyanto, S. (2019). *Pedoman analisis data dengan SPSS.* Yogyakarta: Graha Ilmu.

Wahyudi, W., & Winanto, A. (2018). Development of Project-based Blended Learning (PjB2L) Model To Increase Pre-Service Primary Teacher Creativity. *Journal of Educational Science and Technology (EST)*, *4*(2), 91–102. https://doi.org/10.26858/est.v4i2.5563

Widana. (2020). *Uji Persyaratan Analisis*. Lumajang: Klik Media.