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Effectiveness of Problem-Based Learning in Enhancing Critical Thinking Skills in Science Education: Meta-Analysis

Pradeo Putra Wiratama[1], Wipsar Sunu Brams Dwandaru[2], Heru Kuswanto[3], Silvia Laeli[3], Aris Kurniawan[4]

[1,2,3,4,5]Department of Physics Education, Universitas Negeri Yogyakarta, Indonesia
*Email: pradeoputra.2023@student.uny.ac.id

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ABSTRACT

Purpose – As critical thinking is a key competency in science education, this study employs a meta-analysis to systematically evaluate the effectiveness of the Problem-Based Learning (PBL) model in enhancing students' critical thinking skills. This study analyzed 21 articles published between 2017 and 2024. These articles specifically discuss the effectiveness of PBL implementation in enhancing students' critical thinking skills.

Methodology – The selection criteria included peer-reviewed articles published between 2017 and 2024, which provided explicit numerical data (sample size, mean, standard deviation) and a direct focus on the impact of PBL on critical thinking skills. A random-effects model was chosen due to expected variability among studies, and the effect size was calculated using Hedges' g to ensure robust findings. Data analysis was performed using SPSS version 29 to calculate the summary effect, analyze heterogeneity, construct a forest plot, and identify potential publication bias.

Findings – The meta-analysis revealed a significant improvement in critical thinking skills for students who experienced PBL-based learning compared to conventional methods (summary effect = 0.57, 95% CI = 0.15-1.0, p = 0.01). This shows that 57% of learning with PBL models analyzed has a significant positive effect on students' critical thinking skills. The heterogeneity test indicated (I^2 value = 93,9% > 25%), suggesting moderate variability among the analyzed studies. Funnel plots and Egger's regression tests indicate no risk of publication bias.

Contribution– These findings emphasize the importance of integrating PBL into science curricula to foster critical thinking skills. Educators should consider structured PBL frameworks, while policymakers could support teacher training initiatives to optimize implementation. Future studies may explore longitudinal effects and variations across different educational levels.

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INTRODUCTION

21st-century learning is based on unique characteristics that demand a focus on developing 21st-century skills. This requires students to develop their critical thinking skills in the learning process. Critical thinking skills are one of the most valued competencies. The awareness to think critically brings to life the process of continuous reuse of thinking in an escalation that allows thinking to be oriented both toward the objects of the world and towards the subjective interior, allowing one to determine ideas that provide greater security to the person (Drigas & Mitsea, 2021). This aligns with the findings of Rivas et al. (2022), who suggest that critical thinking makes individuals aware of the mechanisms in decision-making, which always contributes to improving their performance. Critical thinking is also considered reasonable, and reflective thinking focuses on deciding what to believe or do (Ennis, 2011; Rudianti et al., 2021).

In the current educational context, critical thinking skills are becoming increasingly important, especially in science learning, where students are expected not only to memorize facts but also to analyze, evaluate, and create solutions to complex problems. Critical thinking skills enable students to solve problems, innovate, think creatively, and collaborate effectively (Rahayu et al., 2022). Critical thinking skills are essential to support the completeness of learning, which in the 21st century is oriented toward developing a knowledge base and problem-solving strategies (Ningsih et al., 2023). Critical thinking skills need to be developed in education for four reasons. First, it enables learners to respect others as a form of moral education. Second, to prepare students for growth, they must understand themselves through self-sufficiency and self-direction. Third, it is the primary purpose of studying subjects such as math, science, literature, and history. Fourth, it is used to confirm the accuracy of thinking, analysis, and good deliberation in life (Alsarayreh, 2021). Thus, problem-solving-oriented learning is considered effective in providing students with basic understanding and solid concepts.

Critical thinking skills encompass the process of reasoning to solve problems effectively and achieve the desired target. Students who possess high critical thinking competence are generally able to conduct comprehensive analyses, find practical solutions, and draw conclusions based on reflective facts (Sanjaya, 2019). Learning designs that incorporate critical thinking skills and the analysis of real-world problems can enhance students' cognitive understanding of the material studied (Kusumawati et al., 2022). However, survey results indicate that students' critical thinking skills in Indonesia remain relatively low, with 69% of students scoring below 60 (Widyawati et al., 2024). Other data revealed that many students still struggle to apply critical thinking skills in science learning. Only 30% of students demonstrated adequate critical thinking skills, as assessed by standardized evaluations (Putri, 2024; Astuti et al., 2019). These findings suggest a significant issue with students' mastery of critical thinking skills, necessitating further attention and intervention. Therefore, it is essential to employ effective learning methods to train and enhance students' critical thinking skills.

One instructional approach that has proven effective in optimizing students' critical thinking skills is Problem-Based Learning (PBL). Problem-based learning has been shown to develop higher critical thinking skills in students (Satwika et al., 2018; Putri et al., 2020). The PBL model serves as a means for students to hone their critical thinking skills, as the indicators of critical thinking skills align with the stages of the PBL model (Saputri, 2020). The attitude of curiosity and the capacity to think objectively, independently, critically, and analytically can be accommodated by PBL both individually and in groups (Hussin et al., 2021; Basith & Amin, 2021). Similar findings from Syam et al. (2024) indicate that problem-based learning can improve critical thinking skills in high categories. The PBL model is designed to develop students' abilities by solving problems relevant to everyday life. However, not all teachers can design PBL-based learning scenarios, especially in the context of heterogeneous classes (Arifah et al., 2021). Therefore, a careful planning strategy is necessary to implement the Problem-Based Learning (PBL) model effectively, making it an optimal option for enhancing students' critical thinking skills.

Facts on the ground indicate that the primary challenge in science education is the scarcity of approaches that encourage students to think critically and creatively. Traditional learning methods often focus on rote-based teaching, which is insufficient to prepare students for real-world challenges (Yew & Goh, 2016; Kusumatuty et al., 2018). In this context, PBL emerges as a promising alternative, where students are exposed to real-world problems that require problem-solving and collaboration. According to Saputro (2022) and Muslim (2023), Problem-Based Learning (PBL) has been shown to increase student engagement and understanding (Saputro, 2022; Muslim, 2023). In addition, previous research also shows that PBL can improve student learning outcomes; however, there is still a gap in understanding the specific influence of PBL on critical thinking skills, particularly in science learning (Qomariyah, 2019; Gao et al., 2020).

The implementation of the Problem-Based Learning (PBL) model in learning ideally requires significant effort. Therefore, it requires careful consideration of the advantages and disadvantages of its implementation policy. While some studies have shown positive results, others have reported unsatisfactory results, depending on factors such as curriculum design, teacher support, and student engagement (Dolmans et al., 2015; Walker, 2023). Therefore, further research is needed to explore the factors that influence the effectiveness of PBL in improving critical thinking skills, as well as to identify best practices in its implementation (Demirel & Dağyar, 2016; Nasution & Jasmidi, 2023).

Previous studies have demonstrated that PBL is effective in enhancing problem-solving and critical-thinking skills; however, its application is often limited to specific subjects or narrow populations (Desriyanti & Lazulva, 2016; Gunawan, 2022). Research conducted by Eka Putra and Iswantir (2021) revealed that, although the implementation of higher-order thinking Skills (HOTS) through Problem-Based Learning (PBL) faces various challenges, this method effectively enhances students' critical thinking skills. Despite obstacles, PBL successfully develops students' cognitive skills, motivation, and engagement due to its challenging and problem-based nature.

Similarly, research by Nurhayati et al. (2021) demonstrated that PBL improves students' analytical and creative abilities in physics learning. These findings align with prior studies that emphasize the effectiveness of PBL in developing Higher-Order Thinking Skills (HOTS) across various subjects (Kurniawan et al., 2024). Amelia (2019) found that STEM-based PBL significantly enhances students' problem-solving abilities in mathematics, supporting the conclusion that PBL not only improves critical thinking skills but also problem-solving capabilities.

Additionally, a meta-analysis study by Nastiti et al. (2021) estimated the effectiveness of PBL on critical thinking skills. Based on 17 articles analyzed from 2009 to 2019, the effect size of PBL on critical thinking skills was found to be 3.1, indicating a high effect. These findings are consistent with research by Simanjuntak et al. (2020), which emphasized that while PBL can enhance critical thinking skills, its success largely depends on teachers' ability to facilitate discussions and student collaboration. Therefore, further research is necessary to explore the effectiveness of PBL in improving critical thinking skills, particularly through more comprehensive and recent studies. According to Yunita et al. (2020), many studies fail to utilize meta-analysis methods, making it challenging to draw general conclusions about the effectiveness of PBL. Consequently, conducting meta-analyses on the effectiveness of PBL is highly recommended.

By conducting a meta-analysis, this study aims to address the existing gaps by collecting and analyzing data from various previous studies. This approach is expected to provide a clearer understanding of the impact of PBL on critical thinking skills in science education, as well as identify the factors that contribute to the success or failure of PBL implementation (Alkharusi et al., 2013; Guo et al., 2020). The study will also consider variations in study designs, populations, and contexts to offer more comprehensive recommendations for educators and policymakers.

The primary objective of this research is to evaluate the effectiveness of the PBL model in enhancing students' critical thinking skills in science education. Thus, this study is expected to contribute new insights to the field of knowledge, particularly in science education, and provide practical benefits for teachers and educational institutions in designing more effective curricula. Furthermore, the findings of this study are anticipated to serve as a foundation for developing more innovative and responsive teaching strategies tailored to student's needs in this modern era.

METHODOLOGY

This study employs a meta-analysis with a descriptive quantitative approach. The type of meta-analysis used is the group contrast method, which is applied to identify differences in science learning between the PBL model and conventional learning in terms of improving students' critical thinking skills. In conducting the meta-analysis, the researchers performed comparisons and collected data from various prior studies to generate comprehensive conclusions. The articles were collected through online journal exploration using search portals such as Scopus, ERIC, and DOAJ. The reviewed articles were published within the last seven years (2017–2024) to ensure data relevance and accuracy. This research specifically focuses on the impact of the Problem-Based Learning model on students' critical thinking skills. Therefore, article searches were tailored to relevant keywords, such as "Problem-Based Learning," "Critical Thinking Skills," AND "Science."

Determining the criteria for relevant articles is paramount to facilitate the search and selection of articles that are coherent with the topic discussion at a later stage.

Table 1. Eligibility Criteria

Criterion	Inclusion	Exclusion
Article type	Journal articles	Other than journal articles
Journal source	Sourced from Scopus, Eric, and DOAJ	Sourced from Other than Scopus, Eric and DOAJ
Period	Published between 2017 and 2024	Published before 2017
Open access	Journal can be accessed freely (open access)	Journals are not freely accessible (nonopen access)
Study focus	About the effectiveness of the pbl model on students' critical thinking skills	Other than the effectiveness of the pbl model on students' critical thinking skills
Research Methods	Quasi-experimental design of experimental and control classes	Other than quasi-experimental design of experimental and control classes
Research Data	Numerical data that includes sample size, mean value, and standard deviation	Other than Numerical data that includes sample size, mean value, and standard deviation,
Educational institution level	Elementary School, Junior High School, and Senior High School/Vocational School, Collage	Other than Elementary School, Junior High School, and Senior High School/Vocational School, Collage

Journal articles were chosen because of their high credibility that had passed the review process so that they were more reliable than other writings. The criteria for articles analyzed are based on publications in the last seven years (2017-2024) to ensure that the literature is still in accordance with the latest developments, especially the PBL model. Articles indexed in Scopus to ensure the quality and credibility of sources because they are strictly curated. Freely accessible articles make it easy for readers to support the transparency of the research process. Articles that addressed the research topic, sample data, and research methods were selected to maintain conformity with the research objectives while articles that addressed the level of study were selected for their level of relevance to the science topic. The article screening stage is carried out using the PRISMA method, as presented in Figure 1 below

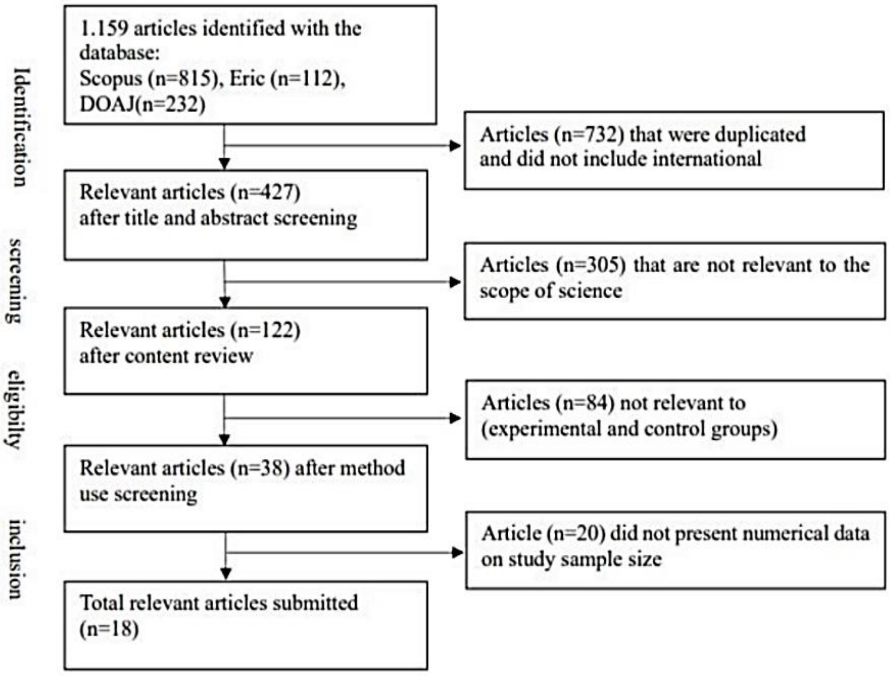

Figure 1. PRISMA Flowchart

Based on the flow chart presented, the first article was collected from various data sources, including Scopus (815), Eric (112), and DOAJ (232). The total number of article references identified according to keywords is 1,159 articles. Second, the removal of duplicate articles. Detected as many as 732 duplicate articles were removed. Third, after removal, 427 relevant articles were identified based on their titles and abstracts. The remaining articles were further examined to ensure their relevance to the criteria, allowing for the deletion of any irrelevant ones. At this stage, 305 articles did not meet the criteria based on the research topic. The remaining articles (122) were re-examined for relevance to the research methods. Fourth, a total of 84 articles were relevant based on the research method (quasi-experimental design of experimental and control groups). Fifth, 20 articles did not present numerical data, including sample size, mean value, and standard deviation. Sixth, relevant articles were submitted. Ultimately, 18 articles were deemed relevant and met the overall inclusion criteria. Of these 18 articles, some presented more than one research result, resulting in a total of 21 final results to be analyzed.

After the articles were collected based on relevant criteria, they underwent statistical analysis. The analysis process began with reading according to the inclusion criteria. The data in the articles were coded manually by indicating the sections that were relevant to the topic. Each relevant section was labeled accordingly. It was then grouped into emerging categories. The analysis was conducted using meta-analysis techniques, employing the random-effects statistical model to generalize to the population. One prerequisite for using the random-effects model is a heterogeneity value of $I2 > 25\%$. The data analysis was conducted using SPSS software. The collected data had varying interval scales (e.g., 0–10 and 0–100). Therefore, the effect size measure used was the standardized mean difference (Borenstein et al., 2009; Card, 2011; Retnawati et al., 2018), standardized using Hedges'g. The SPSS analysis generated various outputs, including a forest plot that provided information on value intervals and standard errors for each article, heterogeneity calculations, a funnel plot to identify publication bias, and an overall conclusion. Thus, this study concludes that the PBL model is effective in enhancing students' critical thinking skills.

FINDINGS

This study analyzed 21 studies derived from 18 primary data articles based on the inclusion criteria. The analysis produced effect sizes and standard errors calculated from sample data, mean values, and standard deviations, as presented in Table 1. Subsequently, a heterogeneity test was conducted to determine the fit between the model and the data. The results of the heterogeneity test are displayed in Figure 1.Within the text of an article, references are to be cited by last name of the author(s) and year of publication. See Table 1:

Table 2. Summary of Research Data, Sample Size, and Standard Deviation

Code	Study	PBL model (experimental)			Conventional (control)			ESg	SEg
		n	M	SD	n	M	SD		
P1	Suhirman et al. (2020)	29	0.35	0.20	28	0.31	0.29	0.16	0.27
P2	Suhirman et al. (2021)	29	0.25	0.20	28	0.28	0.25	-0.13	0.27
P3	Suhirman et al. (2022)	28	0.42	0.18	28	0.31	0.29	0.45	0.27
P4	Suhirman et al. (2023)	28	0.41	0.19	28	0.28	0.25	0.58	0.27
P5	Anazifa & Djukri (2017)	34	59.77	16.05	33	59.45	17.07	0.02	0.24
P6	Mundilarto & Ismoyo (2017)	32	59.84	21.00	32	46.72	16.78	0.68	0.26
P7	Irawati & Sulisworo (2023)	32	86.25	8.33	25	78.00	7.36	1.03	0.28
P8	Kartika et al. (2022)	31	57.90	14.94	27	35.19	15.97	1.45	0.30
P9	Amin et al. (2020)	25	22.80	12.17	25	14.20	10.38	0.75	0.29
P10	Suryawan et al. (2020)	52	64.97	9.72	48	54.43	8.17	1.16	0.22
P11	Arifin et al. (2020)	97	55.87	16.41	102	53.85	16.11	0.18	0.14
P12	Dakabesi & Luoise (2019)	60	37.55	14.13	64	31.84	13.09	0.58	0.18
P13	Pahrudin et al. (2021)	25	70.00	4.41	25	76.20	5.65	-1.96	0.35
P14	Qondias et al. (2022)	88	0.60	0.19	77	0.36	0.19	1.45	0.18
P15	Yolanda (2019)	37	42.16	13.72	37	35.27	11.90	0.70	0.24
P16	Saputro et al. (2020)	22	57.77	2.81	22	48.27	2.80	0.81	0.31
P17	Iqbal & Omeodu (2023)	77	25.29	5.06	72	20.75	6.22	0.46	0.17
P18	Priyadi & Suyanto (2019)	25	78.16	7.12	24	59.33	9.64	2.56	0.39
P19	Cahyani et al. (2023)	30	83.61	7.05	30	80.83	6.40	0.43	0.26
P20	Darmawati & Mustadi (2023)	23	76.87	5.98	23	83.61	8.94	-1.57	0.34
P21	Rohmatin et al. (2022)	24	83.83	3.55	24	63.00	3.27	2.33	0.38

Note:

i) M: The mean of each research sample data,

ii) n: The number of samples from the research data,

iii) SD: The standard deviation of the research sample,

iv) ESg: Effect size as an index presented to summarize the results of the meta-analysis,

v) SEg: Standard error as the basis for determining the actual effect interval

This study employs a random-effects model approach. The random-effects model can be applied when the assumption of heterogeneity is met. The level of heterogeneity is tested by analyzing the I^2 value, which represents the ratio of heterogeneity to the proportion of variation in the summary effect. The I^2 value ranges from 0% to 100%, indicating the degree of observed heterogeneity. The heterogeneity data presented in Figure 2 show a value of 93.9%. Thus, an I^2 value of 93.9% > 25% indicates significant heterogeneity, which is attributed to differences in the actual effect size among studies. High heterogeneity indicates significant variation in how the intervention was implemented or in study characteristics, which may affect the results (Öztürk et al., 2022; Yang et al., 2020). Therefore, the interpretation of the summary effect using the random-effects model is appropriate and to the established criteria. In addition, the H-squared value of 16.389, which is greater than 1, also indicates considerable heterogeneity among the studies. These results, which indicate significant heterogeneity among the studies, corroborate previous findings of substantial variation in results.

Table 3. Heterogeneity Analysis Results

Heterogeneity Measures	
Tau-squared	0.905
H-squared	16.389
I-squared (%)	93.9

The impact of the PBL model on education is illustrated in the forest plot presented in Figure 3. This forest plot displays data from 21 diverse studies analyzed using the random-effects model. The plot consists of blue squares that provide information about the effect size or weight of each study, where the position of each square indicates the location of the effect size for each study. The confidence interval for each study is represented by the horizontal line across the square, with the left endpoint indicating the lower bound and the right endpoint indicating the upper bound.

The forest plot shows a moderate and statistically significant effect size, with a summary effect value of 0.57. This indicates a 57% improvement in critical thinking skills among students who used the PBL model compared to those in conventional learning. However, three studies (13.89%) reported negative effect sizes, suggesting that the critical thinking skills of students in the experimental group were not superior to those in the control group. Overall, the analysis results demonstrate that the PBL model in science education positively impacts the enhancement of students' critical thinking skills.

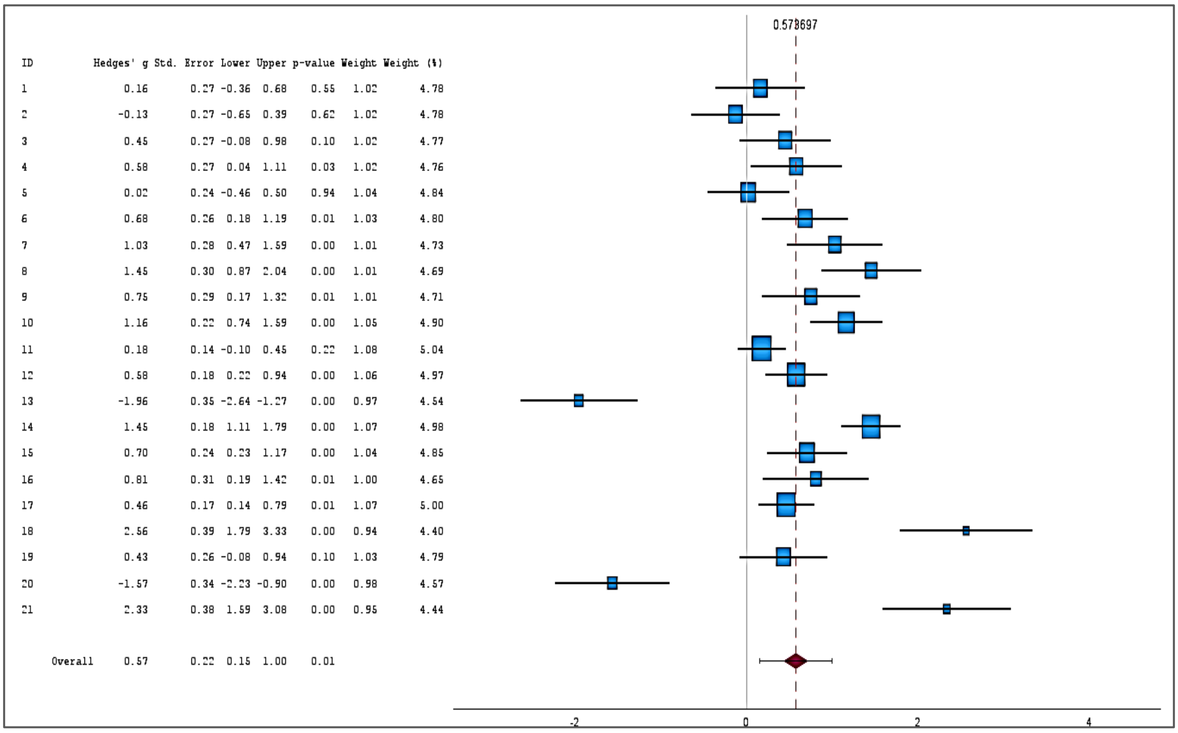

Figure 2. Forest Plot

Numerous studies have been conducted to evaluate the effectiveness of the PBL (Problem-Based Learning) model in science education. Some studies, such as those by Suhirman et al. (2021) with code P2, Pahrudin et al. (2021), and Darmawati & Mustadi (2023), reported negative effect sizes. These findings indicate uncertainty regarding the superiority of the PBL model over conventional teaching methods in specific scientific contexts. In the context of implementation, the application of the PBL model is still dominated by the nature of group collaboration. Through collaboration, each group provides solutions from various sources without combining them into a single project. This results in a less-than-optimal understanding, leaving students' critical thinking skills still lacking (Pahrudin et al., 2021). The quality of the teacher has a significant impact on how the PBL model is intended to be implemented. Teachers can mediate valid and relevant information. The difference in the adaptation process to new information will create an imbalance in students, causing them to experience difficulties in developing critical thinking (Ultaminingsih et al., 202). Students will share what they know based on what they get. Thus, teachers have a crucial role in validating their thinking. However, other studies have reported significant results, including those by Kartika et al. (2022) in physics education, Suhirman et al. (2023) with code P4 in biology education, Dakabesi and Louise (2019) in chemistry education, and Amin et al. (2020) in general science education. These studies demonstrate the significant effectiveness of the PBL model in improving students' critical thinking skills compared to conventional teaching methods. Additionally, the confidence intervals at a 95% significance level bounding each effect size indicate a summary effect range of 0.15 to 1.00. Since the summary effect value is greater than 0 (not including zero), these results suggest a significant difference in critical thinking skills between students taught using the PBL model and those who received conventional instruction.

The analysis of publication bias using a funnel plot is crucial to determine whether conclusions regarding the differences between the PBL (Problem-Based Learning) model and conventional learning in enhancing critical thinking skills are potentially biased. Publication bias may occur due to excessive intervention in the actual effect size or the subjective nature of specific studies. In publication bias analysis, symmetry in the funnel plot can be confirmed by observing the distribution of points within the plot. If there are no significant gaps, particularly in the random-effects model, the symmetry pattern of the effect size can be validated. This symmetry pattern is evident in the funnel plot presented in Figure 4. Further confirmation of publication bias was analyzed using Egger's Regression Method. The Egger test results indicated a t-value of 0.358 and a p-value of 0.724. The null hypothesis regarding funnel plot symmetry is accepted if the p-value is greater than or equal to 0.05. Since p = 0.724 ≥ 0.05, the null hypothesis is accepted, indicating no evidence of missing or unpublished studies. Thus, this analysis suggests no evidence of publication bias in the meta-analysis data. These findings indicate that, under ideal conditions, the PBL model has the potential to enhance students' critical thinking skills in science education. However, the implementation of this model should be adapted to align with ideal or normal conditions in practice.

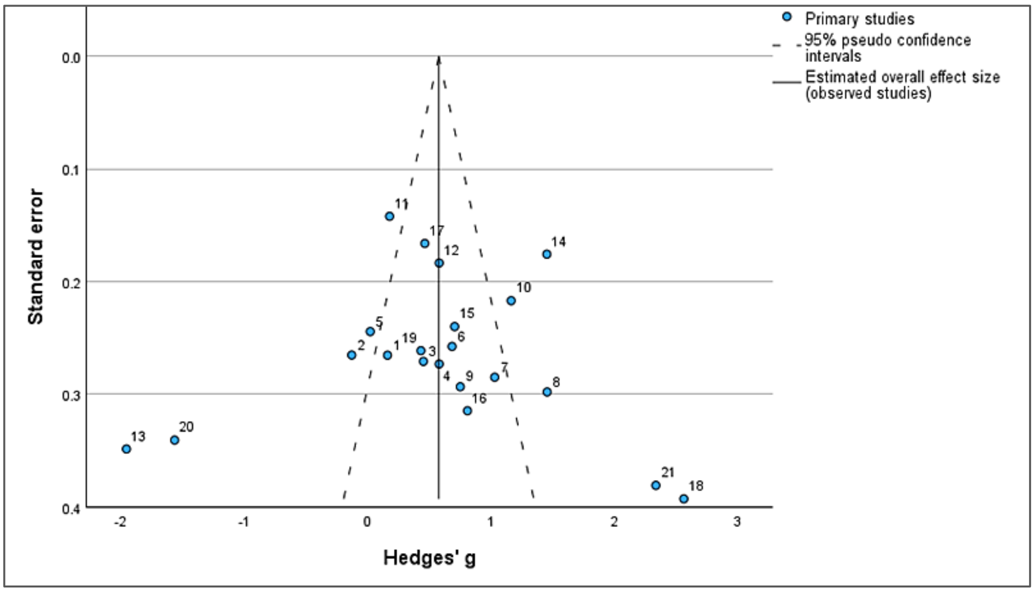

Figure 3. Funnel Plot

DISCUSSION

The integration of the Problem-Based Learning (PBL) model has been widely implemented in the learning process. The impact of problem-based learning on critical thinking skills in science varies depending on the learning needs. This variation is reflected in several studies, such as Kartika et al. (2019), who integrated PBL with local content; Rohmatin et al. (2022), who developed a PBL-based e-module; and Rahmasari & Kuswanto

(2023), who combined PBL with augmented reality technology in learning. According to Astuti (2019), the proper implementation of PBL strategy approaches enables students to solve problems according to their abilities and strategies. This approach encourages students to be more active in group collaboration as they are directly involved in problem formulation and solution-seeking processes. The implementation of PBL provides diverse solutions to real-world problems, which helps students become more confident and better prepared to face challenges in a dynamic and complex world (Dakabesi & Louise, 2019). Therefore, the implementation of problem-based learning, accompanied by careful and logical planning, will significantly enhance the quality of education.

The quality of learning can be represented through the delivery of meaningful scientific content. Meaningful learning offers students positive learning experiences (Arifah et al., 2021). In science education, the PBL model serves as a practical approach to learning. This model can be supported with additional information, such as problem illustrations relevant to local cultures (Kartika et al., 2022; Irawati & Sulisworo, 2023), making the learning process more engaging (Novi et al., 2019). The PBL model also facilitates student learning by emphasizing creativity and collaboration among students. This approach encourages students to engage in problem analysis and construct knowledge through direct interaction with the learning content (Nurrohma & Adistana, 2021; Novi et al., 2019). Moreover, the PBL model simplifies science education by accommodating scientific skills through the systematic application of PBL syntax (Saputri, 2020; Hartati et al., 2022; Saputro et al., 2020). PBL motivates students to analyze, evaluate, and interpret information critically, providing meaningful learning experiences by applying knowledge to real-life situations (Dianita & Tiarani, 2023). With the implementation of the PBL model, the learning process can become more effective and efficient (Arifin et al., 2020; Rohmatin et al., 2022). Challenges encountered during the learning process can also be addressed through this approach. Ideally, the PBL model has a positive impact on learning effectiveness, particularly in enhancing critical thinking skills and mastery of scientific concepts.

The strength of implementing the PBL model in education lies in its ability to encourage students to become more active, creative, and responsive in solving problems during the learning process (Zamzam, 2016; Amin et al., 2020). Research has shown that the application of the PBL model in learning can significantly enhance students' critical thinking skills, especially when the integrated problems are relevant to daily life or based on local wisdom (Kartika et al., 2022). These findings are consistent with previous studies, as reported by Dewi & Kuswanto (2022) and Rahmasari & Kuswanto (2022). According to Septiani et al. (2020) and Aufa et al. (2021), integrating the PBL model with local wisdom not only enhances critical thinking skills but also cultivates attitudes and psychomotor characteristics that support their development. Therefore, adapting PBL model strategies is crucial to achieving a significant impact on students' critical thinking abilities.

Numerous studies have explored the potential of PBL in helping students understand concepts and build knowledge independently. A study by Sidiq et al. (2021) found that implementing higher-order thinking Skills (HOTS)-based questions in science learning significantly enhanced students' critical thinking skills. This finding aligns with research by Kurniawan et al. (2024), which revealed that combining the PBL model with the Demonstration, Literacy, and Experiment methods effectively improved high school students' higher-order thinking skills in the context of Coulomb's law material. Additionally, research by Pertiwi (2022) demonstrated that using PBL-based learning modules increased students' critical thinking skills, with a Normalized Gain score of 0.37, categorized as moderate. These findings suggest that students engaged in problem-based learning can effectively develop their critical thinking abilities. Kusumawardani (2024) further supported this by showing that integrating PBL into a blended learning model significantly enhanced students' critical thinking and problem-solving skills, with a significance value of 0.000, indicating a strong relationship between the teaching method and the achieved outcomes. Moreover, Rafli et al. (2018) concluded that the PBL model is more effective than conventional teaching methods in developing students' mathematical communication skills. Gencer and Doğan (2020) noted that integrating the STEM approach into PBL enhances students' critical thinking skills but also emphasized the need for further research to gain a deeper understanding of classroom dynamics and instructional effectiveness.

The strengths of these studies lie in the use of robust research designs and in-depth analyses, enabling researchers to draw valid conclusions about the effectiveness of PBL (Problem-Based Learning). For example, Abdullah (2024) found a significant relationship between the PBL model and students' critical thinking skills in the context of disaster mitigation, demonstrating the relevance of PBL in real-world learning contexts. However, some limitations must be addressed, such as the restricted generalizability of the findings. Many studies were conducted in limited contexts, making it challenging to apply their results broadly. Yohannes et al. (2021) noted that while improvements in critical thinking skills were observed, variations in sample size and research contexts could influence the outcomes. Therefore, further research with diverse designs is necessary to strengthen these findings. Additionally, Suwandi et al. (2021) emphasized the importance of approaches that account for different types of student intelligence when implementing Problem-Based Learning (PBL). These findings suggest that PBL is not only effective in enhancing critical thinking skills but also flexible enough to adapt to the diverse needs and characteristics of students.

Teachers' creativity in designing PBL (Problem-Based Learning) models is crucial in supporting students in developing independent learning skills. Significantly, students gain holistic learning experiences, which ultimately have the potential to create better learning outcomes. While previous studies have yielded positive results, they also emphasize that the success of PBL heavily depends on the implementation context, proper execution, and adequate technological support. This underscores the importance of carefully planned strategies in implementing PBL to achieve the desired outcomes optimally. With thorough planning, teachers can create a conducive learning environment, promote active student engagement, and ensure the successful implementation of the PBL model.

The implementation of PBL is not only limited to improving the quality of pedagogy but also to changing the essence of the learning experience. The role of PBL extends beyond conventional teaching methods, as it offers personalized learning experiences and accommodates diverse learning needs. The development of critical thinking through the Problem-Based Learning model enables students to engage in active discussions and ask questions that focus on a specific problem, allowing them to build their understanding proactively (Alsarayreh, 2021).

Ultimately, the PBL learning structure presents itself as a purposeful model for modernizing education and deserves to be applied more widely in various learning environments. Aligned with future research directions that also integrate with models proven to be pedagogically useful and policy-relevant, critical thinking skills are potentially central and manageable for 21st-century skills and the future of education and work—a foundation on which stakeholders with diverse visions for the future of education can now build.

CONCLUSION

The distribution of articles on the PBL model of learning and critical thinking skills showed a positive trend. The results of the analysis revealed a significant difference in the critical thinking skills of students who followed Problem-Based Learning (PBL) versus those who followed conventional learning (non-PBL). The group of students who learned using the PBL model showed better critical thinking skills compared to the group using the conventional learning model. Key factors for the effectiveness of PBL teaching in developing critical thinking skills include teacher competence, supportive facilities, and effective learning methods. The effectiveness of PBL depends not only on the method but also on students' education level, such as cognitive readiness and learning style. With good planning, teachers can create a conducive learning environment and support active student engagement. Teachers should also understand classroom dynamics and instructional effectiveness more deeply.

Teachers should also consider two aspects for developing PBL models in science: the allocation of science learning time and the establishment of a learning environment that prioritizes science problems. Learning materials should emphasize locally relevant environmental issues to improve students' critical thinking skills. Therefore, the researcher suggests further specific research, such as exploring how teacher training, curriculum, and infrastructure support can increase the effectiveness of PBL in different contexts, as well as ensuring that all students can benefit maximally from this approach to ensure the successful implementation of PBL.

REFERENCES

Abdullah, I. (2024). The Influence of Problem Based Learning Models on Students' Critical Thinking Ability on Natural Disaster Mitigation Material. *Jurnal Ilmu Pendidikan (JIP) STKIP Kusuma Negara*, 15(2), 159-169. https://doi.org/10.37640/jip.v15i2.1906.

Alkharusi, H., Aldhafri, S., Alnabhani, H., & Alkalbani, M. (2013). The Impact of Students' Perceptions of Assessment Tasks on Self-Eefficacy and Perception of Task Value: A Path Analysis. *Social Behavior and Personality an International Journal*, 41(10), 1681-1692. https://doi.org/10.2224/sbp.2013.41.10.1681.

Alsarayreh, R. (2021). The Effect of Problem-Based Learning Strategy on Developing Critical Thinking Skills. Ilkogretim Online, 20(2).

Amelia, A. (2019). Penerapan Model Pembelajaran Problem Based Learning Berbasis STEM (Science, Technology, Engineering And Mathematics) Untuk Meningkatkan Kemampuan Pemecahan Masalah Matematika. *Jurnal Penelitian, Pendidikan, Dan Pembelajaran*, 14(2), 132-145.

Arifah, N., Kadir, F., & Nuroso, H. (2021). Hubungan antara model pembelajaran Problem-Based Learning dengan kemampuan berpikir kritis pada pembelajaran fisika siswa. Karst*: Jurnal Pendidikan Fisika Dan Terapannya*, 4(1), 14-20.

Astuti, T. P. (2019). Model Problem-Based Learning dengan mind mapping dalam pembelajaran IPA abad 21. *Proceeding of Biology Education*, 3(1), 64-73. https://doi.org/10.21009/pbe.3-1.9

Astuti, T., Nurhayati, N., Ristanto, R., & Rusdi, R. (2019). Pembelajaran Berbasis Masalah Biologi pada Aspek Kognitif: Sebuah Meta-Analisis. *JPBIO (Jurnal Pendidikan Biologi)*, 4(2), 67-74. https://doi.org/10.31932/jpbio.v4i2.473.

Aufa, M. N., Rusmansyah, R., Hasbie, M., Jaidie, A., & Yunita, A. (2021). The effect of using e-module model PBL based on wetland environment on critical thinking skills and environmental care attitudes. *Jurnal Penelitian Pendidikan IPA*, 7(3), 401-407.

Bashith, A., & Amin, S. (2021). The effect of problem-based learning on EFL students' critical thinking skills and learning outcome. Al-Ta Lim Journal, 24(2), 93-102.

Bourgeois-Bougrine, S., Bonnardel, N., Burkhardt, J. M., Thornhill-Miller, B., Pahlavan, F., Buisine, S., & Lubart, T. (2022). Immersive virtual environments' impact on individual and collective creativity. European Psychologist.

Demirel, M. and Dağyar, M. (2016). Effects of Problem-Based Learning on Attitude: A Meta-Analysis Study. *Eurasia Journal of Mathematics Science and Technology Education*, 12(8). https://doi.org/10.12973/eurasia.2016.1293a.

Desriyanti, R. and Lazulva, L. (2016). Penerapan Problem Based Learning pada Pembelajaran Konsep Hidrolisi Garam untuk Meningkatkan Hasil Belajar Siswa. *JTK (Jurnal Tadris Kimiya*), 1(2), 70-78. https://doi.org/10.15575/jta.v1i2.1247.

Dewi, S. S., & Kuswanto, H. (2023). The effectiveness of the use of augmented reality-assisted physics e-module based on pedicab to improve mathematical communication and critical thinking abilities. *JOTSE*, 13(1), 53-64.

Dianita, B., & Tiarani, V. A. (2023). Problem-Based Learning Model with Experiential Learning to Increase Creative Thinking and Critical Thinking Ability. *Jurnal Penelitian dan Pengembangan Pendidikan*, 7(2), 328-335. https://doi.org/10.23887/jppp.v7i2.62254

Dolmans, D., Loyens, S., Marcq, H., & Gijbels, D. (2015). Deep and Surface Learning in Problem-Based Learning: A Review of The Literature. *Advances in Health Sciences Education*, 21(5), 1087-1112. https://doi.org/10.1007/s10459-015-9645-6.

Drigas, A., and Mitsea, E. (2021). 8 pillars X 8 layers model of metacognition: educational strategies, exercises and trainings. Int. J. Online Biomed. Eng. 17, 115–134. doi:10.3991/ijoe.v17i08.23563

Eka Putra, R., & Iswantir. (2021). The Analysis of Implementation of Higher Order Thinking Skills (HOTS) with Problem Based Learning (PBL*). Journal of Physics: Conference Series*, 1779(1). https://doi.org/10.1088/1742-6596/1779/1/012037

Gao, J., Yang, L., Zhao, J., Lian, W., Zou, J., Wang, C., … & Fan, X. (2020). Comparison of Problem-Based Learning and Traditional Teaching Methods in Medical Psychology Education in China: A Systematic Review and Meta-Analysis. *Plos One,* 15(12), e0243897. https://doi.org/10.1371/journal.pone.0243897

Gencer, A. and Doğan, H. (2020). The Assessment of The Fifth-Grade Students' Science Critical Thinking Skills Through Design-Based STEM Education. *International Journal of Assessment Tools in Education,* 7(4), 690-714. https://doi.org/10.21449/ijate.744640

Guo, J., Wang, Q., Li, Y., & Liu, P. (2020). Façade Defects Classification From Imbalanced Dataset Using Meta Learning-Based Convolutional Neural Network. *Computer-Aided Civil and Infrastructure Engineering*, 35(12), 1403-1418. https://doi.org/10.1111/mice.12578

Handayani, Rima, and Dwi Wulandari. 2021. "Modern Assessment dalam Menyongsong Pembelajaran Abad 21 dan Hambatan di Negara Berkembang." *Jurnal Pendidikan Edutama.*8(1): 13. https://doi.org/10.30734/jpe.v8i1.1363.

Hussin, W. N. T. W., Harun, J., & Shukor, N. A. (2021). Problem-based learning to enhance students' critical thinking skills via online tools. Asian Social Science, 15(1), 14-23.

Indarta, Y., Jalinus, N., Abdullah, R., & Samala, A. D. (2021). 21st Century skills: tvet dan tantangan abad 21. Edukatif: *Jurnal Ilmu Pendidikan*, 3(6), 4340-4348.

Iqbal, M., & Omeodu, M. D. (2023). Enhancing Critical Thinking Skills Through Problem-Based Learning in Physics Among Secondary School Students in Sargodha, Pakistan. *Rivers State University Journal of Science and Mathematics Education,* 1(1), 44-52. https://doi.org/10.1016/j.gr.2017.08.001%0.

Kurniawan, A., Kuswanto, H., & Syar, N. I. (2024). Active learning using PBL and DELMAN method to enhance students' Higher Order Thinking Skills (HOTS) on coulomb's law material. *Momentum: Physics EducationJournal,*9(1).Retrievedfromhttp://ejournal.unikama.ac.id/index.php/momentum/article/view/1095.

Kusumatuty, A., Baedhowi, B., & Murwaningsih, T. (2018). The Implementation of Problem Based Learning (PBL) Based E-Book to Improve The Learning Outcome of Vocational High School (VHS) Students. *International Journal of Educational Research Review*, 3(4), 103-110. https://doi.org/10.24331/ijere.454794

Kusumawardani, W. (2024). PBL dalam Blended Learning untuk Meningkatkan Kemampuan Berpikir Kritis dan Pemecahan Masalah. *Jurnal Penelitian Pendidikan IPA*, 10(6), 3303-3308. https://doi.org/10.29303/jppipa.v10i6.7052

Kusumawati, I. T., Soebagyo, J., & Nuriadin, I. (2022). Studi Kepustakaan Kemampuan Berpikir Kritis Dengan Penerapan Model PBL Pada Pendekatan Teori Konstruktivisme. *JURNAL MathEdu (Mathematic Education Journal)*, 5(1), 13-18.

Muslim. (2023). The Impact of Problem-Based Learning on Learning Outcomes Using the Effect Size Calculator for T-Test. *Indonesian Journal of Educational Research and Review*, 6(3), 618-633. https://doi.org/10.23887/ijerr.v6i3.59293.

Nastiti, L. R., Yokhebed, Ramli, M., & Yuliani, H. (2021). Meta-Analysis of The Effectiveness of Problem Based Learning Towards Critical Thinking Skills in Science Learning. *J. Phys.: Conf*. Ser. 1842 012071. https://doi.org/10.1088/1742-6596/1842/1/012071.

Nasution, A. and Jasmidi, J. (2023). Differences in Learning Outcomes of Students Taught With Problem Based Learning Model Assisted by Ispring Suite 10 Media and Powerpoint on Chemical Equilibrium Material. *Jurnal Teknologi Pendidikan Jurnal Penelitian Dan Pengembangan Pembelajaran*, 8(3), 538. https://doi.org/10.33394/jtp.v8i3.7439.

Ningsih, N. W., Polem, M., Azizah, N., Tarsono, T., & Hasbiyallah, H. (2023). Studi Komparatif Model Pembelajaran Contextual Teaching and Learning (CTL) PBL dan Konvensional dalam Meningkatkan Kemampuan Berpikir Kritis Siswa dalam Pembelajaran Abad 21. *JIIP-Jurnal Ilmiah Ilmu Pendidikan*, 6(12), 10001-10007. https://doi.org/10.54371/jiip.v6i12.2468

Novi, N. P., Suarjana, I. M., & Sudarmawan, G. A. (2021). Model Pembelajaran Problem-Based Learning untuk Meningkatkan Hasil Belajar Muatan Pelajaran Ipa Siswa Kelas IV SD. *Jurnal Penelitian Dan Pengembangan Pendidikan*, 5(2), 278-286. https://doi.org/10.23887/jppp.v5i2.37427.

Nurhayati, Wahyudi, & Angraeni, L. (2021). The influence of problem based learning model and critical thinking ability on higher order thinking skills (HOTs) of physics prospective teachers students. *Journal of Physics: Conference Series,* 2104(1). https://doi.org/10.1088/1742-6596/2104/1/012007.

Nurrohma, R. I., & Adistana, G. A. Y. P. (2021). Penerapan Model Pembelajaran Problem-Based Learning Dengan Media Elearning Melalui Aplikasi Edmodo Pada Mekanika Teknik. *Jurnal Ilmu Pendidikan,* 3(4), 1199–1209. https://doi.org/10.31004/edukatif.v3i4.544.

Öztürk, B., Kaya, M., & Demir, M. (2022). Does inquirybased learning model improve learning outcomes A second-order meta-analysis. *Journal of Pedagogical Research*, 6(4), 201-216. https://doi.org/10.33902/JPR202217481

Pertiwi, H. (2022). Developing Science Module of Problem-Based Learning to Improve Critical Thinking Skill. *Physics and Science Education Journal (PSEJ*), 1-8. https://doi.org/10.30631/psej.v2i1.1213.

Pratiwi, S. N., Cari, C., & Aminah, N. S. (2019). Pembelajaran IPA abad 21 dengan literasi sains siswa. *Jurnal Materi dan Pembelajaran Fisika,* 9(1), 34-42.

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. *JIPI (Jurnal IPA & Pembelajaran IPA), 4(2),* 193-204. https://doi.org/10.24815/jipi.v4i2.17859.

Putri, F. (2024). Meta-Analysis of Problem Based Learning Models on Physics Problem Solving Abilities. *Edufisika Jurnal Pendidikan Fisika*, 9(1), 74-80. https://doi.org/10.59052/edufisika.v9i1.32648.

Qomariyah, S. (2019). Effect of Problem Based Learning Learning Model to Improve Student Learning Outcomes. *International Journal of Educational Research Review*, 4(2), 217-222. https://doi.org/10.24331/ijere.518056.

Rafli, M. and Syahputra, E. (2018). Influence of Problem Based Learning Model and Early Mathematics Ability to Mathematical Communication Skills and Self-Confidence in Junior High School. *American Journal of Educational Research*, 6(11), 1539-1545. https://doi.org/10.12691/education-6-11-12.

Rahayu, R., Iskandar, S., & Abidin, Y. (2022). Inovasi pembelajaran abad 21 dan penerapannya di Indonesia. *Jurnal Basicedu*, 6(2), 2099-2104.

Rahayu, R., Iskandar, S., & Abidin, Y. (2022). Inovasi Pembelajaran Abad 21 dan Penerapannya di Indonesia. *Jurnal Basicedu*, 6(2), 2099–2104. https://doi.org/10.31004/basicedu.v6i2.2082/

Rahmasari, A., & Kuswanto, H. (2023). The Effectiveness of Problem-Based Learning Physics Pocketbook Integrating Augmented Reality with the Local Wisdom of Catapults in Improving Mathematical and Graphical Representation Abilities. *Journal of Technology and Science Education*, 13(3), 886-900. https://doi.org/10.3926/jotse.1962.

Rivas, S. F., Saiz, C., & Ossa, C. (2022). Metacognitive strategies and development of critical thinking in higher education. *Frontiers in psychology*, 13, 913219.

Sanjaya, F. (2019). Efektivitas Pembelajaran Pendekatan Saintifik Terhadap Kemampuan Berpikir Kritis Siswa (Studi Kuasi Eksperimen Pada Mata Pelajaran Ips Kelas Vii D Di Smpn 1 Pacet - Cianjur). Oikos: *Jurnal Kajian Pendidikan Ekonomi Dan Ilmu Ekonomi*, 3(1), 19. https://doi.org/10.23969/oikos.v3i1.1405.

Saputri, M. A. (2020). Penerapan Model Pembelajaran Problem-Based Learning Untuk Meningkatkan Kemampuan Berfikir Kritis Siswa Kelas V Sekolah Dasar. *Jurnal Pendidikan Dan Konseling (JPDK)*, 2(1), 92–98. https://doi.org/10.31004/jpdk.v1i2.602.

Saputro, S. (2022). The Impact of Problem Based Learning on Learning Outcomes in Nursing Students. *International Journal of Multidisciplinary Research and Analysis,* 05(10), 2784-2788. https://doi.org/10.47191/ijmra/v5-i10-29.

Satwika, Y. W., Laksmiwati, H., & Khoirunnisa, R. N. (2018). Penerapan model Problem-Based Learning untuk meningkatkan kemampuan berfikir kritis mahasiswa. *JP (Jurnal Pendidikan): Teori dan Praktik*, 3(1), 7-12.

Septiani, F., Sriyati, S., & Amprasto. (2020). Implementasi Bahan Ajar Berbasis Kearifan Pertanian Lokal di Binjai untuk Meningkatkan Literasi Lingkungan Mahasiswa. Kemajuan dalam Penelitian Ilmu Sosial, Pendidikan dan Humaniora, 399, 80–85. https://doi.org/10.2991/assehr.k.200130.086

Sholihah, T. M., & Lastariwati, B. (2020). Problem-Based Learning to increase competence of critical thinking and problem solving. *Journal of Education and Learning (EduLearn),* 14(1), 148-154.

Sidiq, Y., Ishartono, N., Desstya, A., Prayitno, H., Anif, S., & Hidayat, M. (2021). Improving Elementary School Students' Critical Thinking Skill in Science Through HOTS-Based Science Questions: A Quasi-Experimental Study. *Jurnal Pendidikan IPA Indonesia*, 10(3), 378-386. https://doi.org/10.15294/jpii.v10i3.30891.

Simanjuntak, M., Purba, C., Panggabean, B., Mustafa, A., & Hutahaean, J. (2020). The Effect of Problem Based Learning (PBL) Towards Critical Thinking Used Computer Simulation. *Proceedings of the 7th Mathematics, Science, and Computer Science Education International Seminar*, *MSCEIS 2019*. https://doi.org/10.4108/eai.12-10-2019.2296467.

Simon, A. (2000). Perceptual comparisons through the mind's eye. *Memory & Cognition*, 23(2), 635-647.

Suci, S. K., Muhaimin, M., & Zurweni, Z. (2022). The implementation and effect of Problem-Based Learning based on local wisdom toward students' communication and critical thinking ability on temperature and heat topic. *Jurnal Penelitian & Pengembangan Pendidikan Fisika,* 8(1), 165-174.

Suwandi, A., Sahidu, H., & Gunada, I. (2021). Effectiveness of Problem-Based Learning Model Devices with Multiple Intelligences Approach to Improve Learners' Physics Problem-Solving Skills. *Jurnal Penelitian Pendidikan IPA*, 7, 238-243. https://doi.org/10.29303/jppipa.v7ispecialissue.1064.

Syam, Y. R., Kurniasih, S., & Retnowati, R. (2024). Improving Students' Critical Thinking Skills Using the Problem-Based Learning Model Assisted by Virtual Laboratories. *Jurnal Ilmiah Pendidikan Dan Pembelajaran*, 8(1), 27-33.

Thornhill-Miller, B., Camarda, A., Mercier, M., Burkhardt, J. M., Morisseau, T., Bourgeois-Bougrine, S., & Lubart, T. (2023). Creativity, critical thinking, communication, and collaboration: assessment, certification, and promotion of 21st century skills for the future of work and education. *Journal of Intelligence*, 11(3), 54.

Utaminingsih, M., Widjanarko, M., & Ismaya, E. A. (2022). The effect of problem-based learning assisted by peer tutoring on student's critical thinking ability. *ANP Journal of Social Science and Humanities*, 3, 101-106. https://doi.org/10.53797/anp.jssh.v3sp2.14.2022

Walker, A. (2023). Conducting Problem-Based Learning Meta-Analysis: Complexities, Implications, and Best Practices. *Interdisciplinary Journal of Problem-Based Learning*, 17(2). https://doi.org/10.14434/ijpbl.v17i2.35844.

Widyawati, A., Kuswanto, H., & Prodjosantoso, A. K. (2024). E-Comic Based on SETS: A Digital Learning Media to Improve Student's Character and Critical Thinking Skills. *International Journal of Religion*, 5(2), 47-56.

Yang, J. M., Sung, Y. T., & Chang, K. E. (2020). Use of meta-analysis to uncover the critical issues of mobile inquiry-based learning. *Journal of Educational Computing Research*, 58(4), 715-746. https://doi.org/10.1177/0735633119879366

Yew, E. and Goh, K. (2016). Problem-Based Learning: An Overview of Its Process and Impact on Learning. Health Professions Education, 2(2), 75-79. https://doi.org/10.1016/j.hpe.2016.01.004.

Yohannes, Y., Juandi, D., & Tamur, M. (2021). The Effect of Problem-Based Learning Model on Mathematical Critical Thinking Skills of Junior High School Students: A Meta-Analysis Study. *JP3I (Jurnal Pengukuran Psikologi Dan Pendidikan Indonesia),* 10(2), 142-157. https://doi.org/10.15408/jp3i.v10i2.17893.

Yunita, Y., Juandi, D., Tamur, M., Adem, A., & Pereira, J. (2020). A Meta-Analysis of The Effects of Problem-Based Learning on Students' Creative Thinking in Mathematics. *Beta Jurnal Tadris Matematika*, 13(2), 104-116. https://doi.org/10.20414/betajtm.v13i2.380

Zamzam, K. F. (2016). Pendekatan Problem-Based Learning untuk mengembangkan kemampuan berpikir kritis mahasiswa. PEDAGOGIA*: Jurnal Pendidikan*, 5(2), 279-286.