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Meta-Analysis: The Influence of the PBL Learning Model on Students' Critical Thinking Ability in Physics Learning

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Abstract

The influence of the Problem Learning (PBL) model on students' critical thinking capacity in physics learning has been widely researched. The research aims to determine the effect size of each journal that will be used as a research sample. The method used in this research is meta-analysis, using ten journals as samples. OpenMEE was used to analyse data to obtain effect size values. The effect size test shows that the use of the PBL model has a general influence on students' critical thinking abilities of 2.191, which shows that the use of the PBL model has a very positive influence on students' critical thinking abilities in physics education. Using PBL in teaching and learning can improve students' analytical and problem-solving skills.

Keywords: critical thinking ability; meta-analysis; problem-based learning; science learning

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INTRODUCTION

Problem-Based Learning (PBL) is an approach to solving real problems to understand scientific concepts. This learning model encourages students to develop critical thinking skills, work together, and solve problems in real-life situations. PBL can also increase students' activities and competencies and provide significant learning outcomes (Maulidiya & Nurlaelah, 2019; Suharno et al., 2022; Sujanem & Putu Suwindra, 2023; Susilawati, 2016).

PBL has several advantages over traditional learning. These advantages include: (1) Through PBL, students are involved in group discussions, research, and presentations, all of which require active involvement to achieve in-depth understanding (Pristianti & Prahani, 2023); (2) This model encourages students to develop critical thinking skills through solving real problems (Karmila et al., 2021); (3) Scientific communication skills: Through PBL, students can develop scientific communication skills and learn to work together to solve problems (Karmila et al., 2021); and (4) Intrinsic motivation: PBL can increase students' intrinsic motivation because they are involved in solving relevant and real problems (Karmila et al., 2021; Marcinauskas et al., 2024). Several studies show that PBL can provide significant learning outcomes and better learning activities (Suharno et al., 2022).

The PBL model can impact students' scientific literacy abilities. The impact of PBL on students' scientific literacy abilities should be seen in three areas of learning outcomes: cognitive, affective, and psychomotor (Pasiri, 2023; Utami & Setyaningsih, 2022), namely: (1) Cognitive: PBL builds the scientific literacy abilities of the trial class, which is realised by the PBL stage which expects students to read a lot. (2) Affective: PBL stimulates students' interest in the material, which can expand the value of proficiency in a feeling-filled space. (3) Psychomotor: PBL can foster students' ability to collect and organise information and introduce unclear results, encouraging students' logical educational perspective.

PBL provides a real-world context for learning, allowing students to identify and solve scientific problems relevant to everyday life situations or scientific contexts (Barbara et al., 2001). Through PBL, students can develop critical thinking skills in evaluating information, identifying problems, and producing appropriate solutions (Hidayati & Wagiran, 2020; Karmila et al., 2021). PBL encourages students to apply their knowledge to real-world problems, fostering a deeper understanding of scientific concepts (Barron & Wells, 2013). The PBL model also supports students in understanding the connections between concepts and principles, improving their conceptual development and correcting misconceptions (Karmila et al., 2021). Additionally, PBL can increase students' intrinsic motivation by engaging them in solving relevant and real problems (Barbara et al., 2001; Hidayati & Wagiran, 2020).

PBL is an approach to teaching that emphasises problem-solving and critical thinking skills. PBL provides opportunities for students to develop critical thinking skills by engaging them in real-world problem-solving activities. A study found that through PBL, students can develop inquiry skills, which then encourage the emergence of critical thinking abilities (Asri et al., 2024). Additionally, PBL can improve students' problem-solving abilities and learning motivation. This aligns with several scholars' opinions that PBL can train students to have critical thinking skills, solve problems, and build their knowledge (Karmila et al., 2021).

The search results prove that PBL positively impacts students' critical thinking abilities, problem-solving skills, and learning motivation in physics education. PBL allows students to strengthen connections between concepts in science material by relating science concepts to practical applications in everyday life situations or scientific contexts, thereby deepening their understanding of these concepts. Additionally, PBL can improve students' problem-solving abilities and learning motivation, as well as train students to have critical thinking skills and the ability to solve problems (Asri et al., 2024; Karmila et al., 2021).

The integration of science concepts in PBL can be achieved through several steps (Rihhadatul'aysi et al., 2020): (1) During the PBL learning process, new concepts in science are linked to concepts that students already have, allowing them to understand the relationship between concepts. (2) Teachers use concrete media to help students visualise science concepts, making it easier for students to understand and integrate them. (3) The STM approach can be used in science learning through PBL, where students are invited to understand and apply science concepts in everyday life and their environment. By following these steps, integrating science concepts in PBL can help students deepen their understanding of science concepts and relate them to practical applications in everyday life. This approach can improve students' problem-solving abilities and learning motivation and train them to have critical thinking skills (Karmila et al., 2021; Rihhadatul'aysi et al., 2020).

Applying the PBL model has proven to improve students' critical thinking abilities. Several studies show that PBL can improve students' critical thinking abilities. A study by (Asri et al., 2024) shows that implementing PBL can improve students' critical thinking abilities. Another research by (Mulyanto et al., 2018) also demonstrates the effectiveness of PBL in enhancing students' critical thinking skills. These findings suggest that the application of the PBL model has been proven effective in improving students' critical thinking skills at various educational levels and subjects (Asri et al., 2024; Hidayati & Wagiran, 2020; Mulyanto et al., 2018; Santuthi et al., 2020; Yu & Zin, 2023). PBL provides active learning conditions for students, enabling them to analyse problems, find solutions, and manage learning through planning, monitoring, and problem-solving (Yu & Zin, 2023).

METHOD

This research is a systematic literature review using meta-analysis methods. The population used in this research were national and international journals regarding the influence of the PBL model on students' critical thinking abilities. The sample used was 23 research articles from selection based on inclusion criteria. The meta-analysis stages used in this research adapt the meta-analysis steps described by DeCoster and are presented in the diagram in Figure 1 (Decoster, 2009).

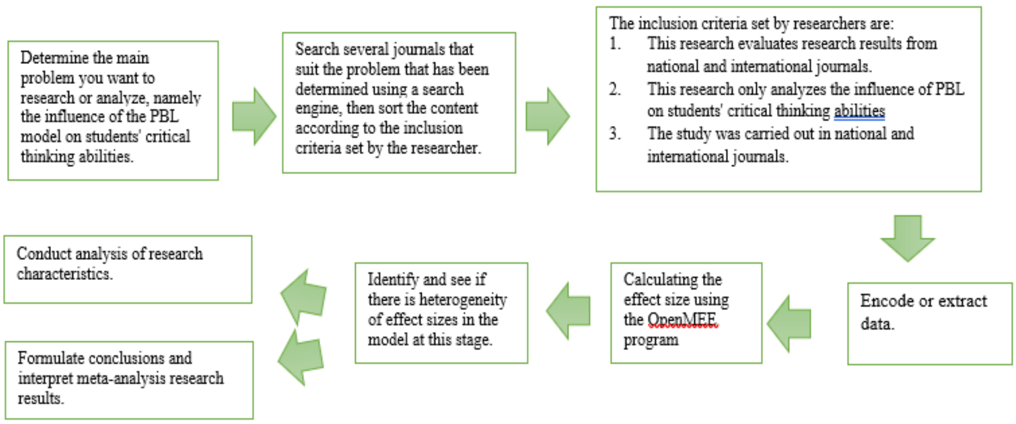

Figure 1 Meta-analysis steps

Next, after the research selection process was complete, the data extraction process was carried out. This process was carried out by researchers and a coder so that the empirical data extracted from primary research is valid and obtained through the results of inter-reliability tests. In this test, the interpretation of agreement values between coders was included in the good agreement category to use the data for further analysis. This step is important for meta-analysis method researchers to pay attention to because it is related to a rigorous quantitative research process and is closely related to the reliability of the analysis results.

The meta-analysis method is quantitative and closely related to the use of Effect Size (ES). ES represent the strength of the impact between the dependent and independent variables, and their values can be compared across studies. The relationship between variables discussed in this research is the relationship between learning class, year of learning, sample size, length of treatment, and its influence on the effectiveness of PBL in improving students' critical thinking abilities. The ES calculation is calculated using the Hedges'g formula (Borenstein, Hedges, Higgins, & Rothstein, 2009; Yohannes et al., 2021), which is a development of the effect size formula proposed by Glass (1981). The ES calculation process is carried out with the help of the OpenMEE program, which can process empirical data such as mean, standard deviation, sample size, t value, and p-value, which can later be used as the effect size value. Next, the ES was interpreted using the ES category (Yohannes et al., 2021) in Table 1.

Table 1 Effect Size (ES) categories

ES	**Effect Size Category**
$ES \leq 0.15$	Negligible effect
$0.15 < ES \leq 0.40$	Small effect
$0.40 < ES \leq 0.75$	Moderate effect
$0.75 < ES \leq 1.10$	High effect
$1.10 < ES \leq 1.45$	Very high effect
$1.45 < ES$	High effect

RESULT AND DISCUSSION

This meta-analysis uses ten journals from several journal sources related to the PBL model of students' critical thinking abilities. The data obtained by calculating the effect size of each journal is presented in Table 2.

Table 2 Effect Size (ES) categories

Studi	**ES**	**Category**
J1	0.687	Moderate effect
J2	0.000	Negligible effect
J3	0.726	Moderate effect
J4	0.245	Small effect
J5	0.729	Moderate effect
J6	0.669	Moderate effect
J7	1.094	High effect
J8	2.484	High influence
J9	0.747	Moderate effect
J10	2.996	High influence
Average	2.191	High influence

Based on the ES in Table 2, there are 5 (five) studies with moderate influence, 2 (two) studies with high influence, 1 (one) study with very small influence, and 1 (one) study with negligible influence. Based on the fixed-effect model, the total influence of the PBL model combination on students' critical thinking abilities as a whole is 2,191 and is included in the high influence category.

The publication bias test is the next step in the meta-analysis procedure, and it is used to determine whether any studies are systematically distinct from the others. The Forest Plot results were examined for the publication bias test. Figure 2 displays the flow diagram.

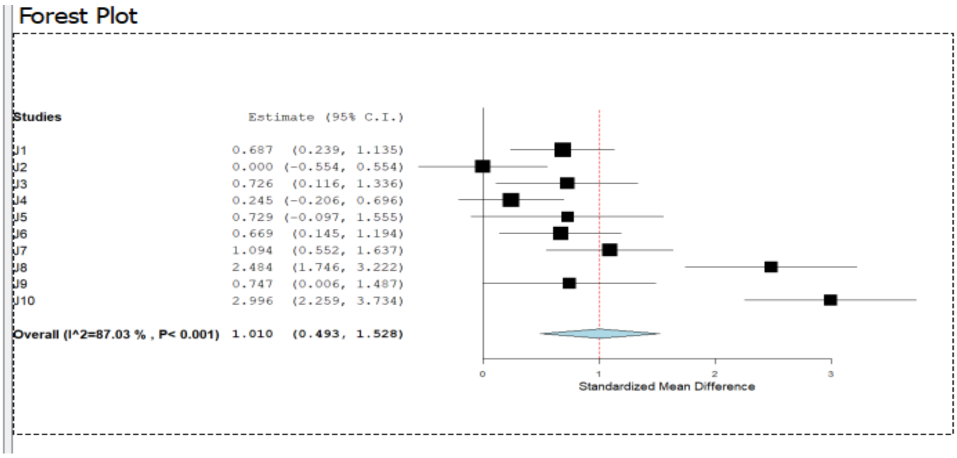

Figure 2 Forest plot of ES distribution

All ES are distributed asymmetrically, as shown in Figure 2. These calculations show no publication bias in any of the studies included in the meta-analysis. A Continuous Random-Effects Model is then applied to determine whether further research is required. The Continuous Random-Effects Model test's findings are presented in Table 3.

Table 3 Continuous random-effects model

Random-Effects				
Estimate	**Lower bound**	**Upper bound**	**Std. error**	**p-Value**
1.010	0.493	1.528	0.264	< 0.001

Based on Table 3, the next step is to identify the heterogeneity of the effect size distribution. Based on the OpenMEE output, the heterogeneity values are presented in Table 4.

Table 4 Heterogeneity distribusi ES

Heterogeneity			
tau^2	Q(df=22)	Het. p-Value	I^2
0.597	69.404	< 0.001	87.032

Table 4 shows that the I2 value is 87,032, meaning that the ten journals analysed are very diverse. Therefore, the estimation model used in this analysis is the random effect model. The effect size obtained in this random model was 0.597 (medium effect category).

The results of the agreement test analysis between coders show that the extracted data is in the good agreement category so that the data can be used in further analysis. This data will be processed and analysed by interpreting the effect size value. The effect size calculation process was carried out with the help of OpenMEE. Statistical data, such as mean value, standard deviation, sample size, t-value, and p-value from the experimental and comparison/control groups, will be entered into the program and processed into an effect size. Apart from that, OpenMEE can also present test results for publication bias so that it can be seen whether there is primary research that has a bias, and primary research that is significantly different can be excluded from the analysis process.

The effect size is 0.59 (the effect is very moderate). In line with research conducted by Taufik et al. (2022), the problem-based learning model influences students' critical thinking abilities in learning. In the analysis of publication bias, these weaknesses can be overcome so that significantly in the analysis, it is found that the application of the PBL model has a high influence on students' critical thinking abilities in science learning. The established inclusion criteria (Sutiarso, 2021) can cause differences. Apart from that, the findings of this research are very different from the results of research (Mustaffa, 2014), which found that implementing PBL was less practical than the conventional model because students were already used to the conventional model. These differences can arise due to differences in research subjects and external factors that researchers cannot fully control. Overall, applying the PBL model has a higher influence on students' critical thinking abilities than conventional learning models. Thus, it can be said that the use of the PBL model is recommended because it has a positive effect on increasing students' critical thinking abilities.

Implementing the PBL model necessitates a considerable improvement, leading to this outcome. The ideal number of meetings is more than four until students are accustomed to PBL syntax's activity steps (Yohannes et al., 2021). According to Yew & Goh (2016), problem orientation in the PBL step also necessitates adequate individual and group investigation time to achieve the desired learning outcomes. Therefore, schools must consider the length of treatment for the PBL model to impact students' capacity for critical thinking significantly.

The problem-based learning model is applied by bringing problems into play during the learning process (Alrahlah, 2016; Chen, 2014). The problems can encourage students to think critically (analyse, evaluate, and make or draw conclusions (Gholami et al., 2016; Şendağ & Odabaşi, 2009). Students in PBL need to understand the material and study, assess, and decide on sample material to find answers to these problems.

The PBL model has been found to influence students' critical thinking abilities in physics learning positively. A study conducted at IKIP PGRI Pontianak found that applying the PBL model improved students' higher-order thinking skills in optical materials, particularly for those with high critical thinking skills (Nurhayati et al., 2021). Another research aimed to determine the effect of PBL on the critical thinking abilities of physics students at the University of Flores (Liu & Doa, 2023). The results of these studies suggest that the PBL model effectively enhances students' critical thinking skills in the context of physics education.

PBL, in its learning process, uses seven steps, namely (1) clarifying unknown terms, (2) defining the problem, (3) brainstorming, (4) analysing the problem, (5) formulating learning objectives, (6) independent learning and (7) reporting the results of problem-solving (Camp, 2014). The steps in PBL are sufficient to stimulate students' critical thinking on each problem topic so that they require solutions appropriate to the material being taught (Mustofa & Hidayah, 2020). Problem-based learning provides information to students using perception and delivery methods. This method trains students to find answers to broader problems. Observing and identifying also helps students understand the experiences involved with the critical thinking process; this cycle can implicitly further develop thinking skills. Students' critical and creative thinking abilities can be seen in their ability to understand problems and find solutions (Kardoyo et al., 2020).

Based on the discussion, it can be seen that the application of the PBL model influences students' critical thinking abilities in science learning. Therefore, the findings in this research are relevant information at this time. Therefore, researchers recommend that teachers use the PBL model in science learning in schools because it influences critical thinking skills. Apart from that, researchers suggest that the ideal duration for implementing PBL in learning needs to be considered because it will have a more positive impact. Apart from these research findings, many active learning models still significantly impact students' critical thinking abilities, especially in science learning.

The influence of PBL on students' science learning abilities can also be seen in improving students' communication skills, as shown in research showing that the PBL learning model is more effective in improving students' communication skills (Andayani et al., 2019). In addition, the metacognitive approach inserted in PBL learning can trigger students' cognitive awareness, which influences students' mathematical problem-solving abilities (Rizka et al., 2018).

CONCLUSION

Based on the results of data analysis and discussions carried out on ten articles, the use of PBL in science learning with an average effect size of 2.191 has a high influence. Increasing critical thinking skills is also influenced by introducing PBL into the classroom. Thus, using PBL in science education can help students improve their skills.

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