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[Review Article]

THE EFFECT OF PROBLEM-BASED LEARNING ON SCIENCE LITERACY IN PHYSICS EDUCATION: A META-ANALYSIS

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ABSTRACT

This meta-analysis aims to analyze the impact of Problem-Based Learning (PBL) on students' science literacy in physics education. The study uses a descriptive quantitative method with a meta-analysis approach on 16 national journal articles that meet inclusion and exclusion criteria. Results indicate a significant average effect size of 1.72 (large category), with senior high school (effect size 1.95) having the most critical impact. In contrast, junior high and elementary schools have effect sizes of 0.77 and 0.48, respectively. Problem-based learning significantly impacts the Solar System, Heat & Temperature, and Global Warming. Furthermore, the implementation factor with the most significant and consistent impact is PBL combined with learning media, especially edugames and interactive simulations, with an average effect size of 1.76 (large category). These results suggest that PBL in physics education can significantly improve students' science literacy, especially in higher education levels and with appropriate learning media.

Keywords: *Problem-Based Learning*, *Science Literacy*, *Meta-analysis*, *Physics Learning*, *Effect Size*

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1. INTRODUCTION

Science literacy is critical for comprehending and describing scientific phenomena, particularly in physics education. It encompasses the capacity to learn scientific concepts, engage in critical analysis, and apply scientific knowledge to practical, real-world contexts. However, students' science literacy in Indonesia is still below average. The 2023 PISA results indicate that science literacy in Indonesia remains the lowest among OECD countries (OECD, 2023). Additionally, data from National Examinations suggest that physics is one of the topics with low pass rates, especially in mechanics, waves, and optics concepts (Kemendikbud, 2019). This demonstrates that many students struggle to grasp fundamental physics concepts and apply them to real-world problems (Elia & Nana, 2020; Harahap & Juliani, 2019; Mukharomah et al., 2021).

Several factors contribute to the low science literacy of Indonesian students. These include unsuitable teaching methods, an emphasis on rote learning rather than deep understanding, and students' difficulties in interpreting data and evidence scientifically (Fuadi et al., 2020; Permata Sari et al., 2022; Yusmar & Fadilah, 2023). Research by Wulandari et al. (2019) found that students frequently memorize things without fully understanding them, while teachers still rely on conventional teaching methods. Furthermore, students' inability to understand basic experimental data, such as reading graphs from physics class observations, indicates low science literacy. According to research by Pratiwi et al. (2019), only 29.9% of students could correctly answer velocity-time graph questions on linear motion concepts. If this issue is not resolved quickly, students will find it progressively challenging to grasp and utilize scientific concepts in real-life contexts, analyze data, and solve problems. Thus, an interactive learning approach is required to improve student engagement and comprehension.

Many studies have shown the advantageous impact of PBL on students' science literacy. Research by Lendeon & Poluakan (2022) indicates that PBL can enhance science literacy related to temperature and heat concepts, while Muladi & Suwarna (2024) confirm its effectiveness on optical instrument topics. This indicates that PBL helps students understand physics concepts more deeply through active engagement in scientific investigation and can also be applied across various physics topics. Additionally, Ardianto & Rubini (2016) found that PBL also aids students in developing skills to describe scientific phenomena, assess and formulate investigations, and interpret data.

Even though many studies show the effectiveness of PBL, results still vary depending on the context and factors involved. This study employs a meta-analysis method to integrate different findings and gather more solid information about the effect of PBL on students' science literacy in physics education. The discovery of factors influencing PBL's success is made possible by the meta-analysis, which improves validity and produces more thorough results. Therefore, this study aims to quantify the degree to which PBL influences students' science literacy and to identify the factors that influence its efficacy.

2. METHOD

The method used in this research is quantitative research with a meta-analysis approach. This approach was chosen because it makes combining quantitative data from several research methods easier, leading to thorough and reliable conclusions regarding how the PBL paradigm affects students' science literacy. Moreover, meta-analysis leverages statistical data such as effect size, quantifying the magnitude of the observed impact, thus aligning well with the research objectives.

This meta-analysis analyzed 16 national journal articles published over the last five years (2019-2024). National journals were selected for their tendency to supply data pertinent to the educational contexts being studied, in contrast to many international journals that frequently lack the necessary data for calculating effect sizes, including means, standard deviations, and sample sizes. The inclusion and exclusion criteria applied to the journal articles are detailed in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
1. Articles published within the last 5 years (2019-2024)	1. Articles that lack the required statistical data, such as mean, standard deviation, and sample size
2. The focus of the subject matter is physics and science	2. Articles with qualitative or descriptive research designs
3. Research articles use a quantitative approach and provide statistical data for calculating effect sizes, such as mean, standard deviation, and sample size.	3. Articles not relevant to the focus on science literacy or Problem-Based Learning and types of documents such as dissertations and theses.

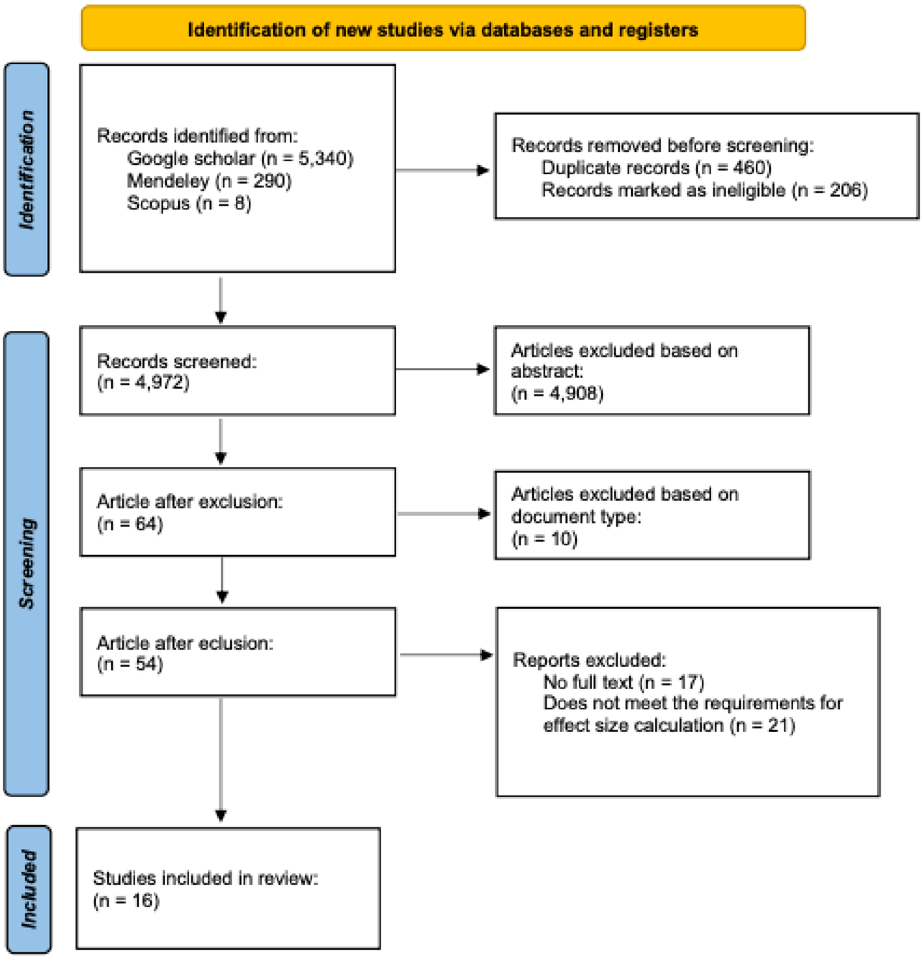
The article search procedure used several databases, keywords, and particular search criteria. More detailed information about the search strategy can be found in Table 2 below.

Table 2. Article Search Strategy

Search Aspects	Description
Databases	Google Scholar, Sinta, and Scopus
Keywords	"*Problem-Based Learning*" AND "*Science Literacy*"
Search Period	December 2024 to January 2025
Language Restrictions	Articles in Indonesian and English

An initial search found 5638 items from several databases, including Google Scholar, Sinta, and Scopus. These articles were converted to Microsoft Excel for data organizing, and 666 items were eliminated owing to duplication and failing to match the initial criteria. After that, 4972 articles passed through a three-stage screening procedure. The first exclusion stage was based on abstracts; papers matching the abstract requirements were moved to the following list. The second stage entailed document-type exclusion, with dissertations and theses being incompatible. The final stage rejected articles that were unavailable in full text or did not match the criteria for calculating effect size. Following this process, 16 papers met the analysis's inclusion and exclusion criteria. A flowchart of the selection stages can be viewed in Figure 1 for a more precise illustration of the article selection process.

Figure 1. PRISMA Flow Diagram 2020



This meta-analysis uses a fixed-effect model, which does not account for trial variability. Statistically, all studies are assumed to come from the same population and measure the same variables (Retnowati, 2018). This methodology allows for a total of findings from multiple studies that match the inclusion criteria while ignoring inter-study variances. Data was thoroughly coded throughout the procedure to guarantee consistency and relevance to the research aims. Statistical data, such as means, standard deviations, and sample sizes, were extracted from articles that satisfied the inclusion requirements. To verify data validity, each piece of information was checked by going back to the source articles and cross-referencing the data with the articles.
The steps to calculating the effect size are as follows.

2.1 Effect size Cohen's d

The following equation calculates the effect size of the experimental and control groups.

$$d = \frac{\overline{X_e} - \overline{X_c}}{SD_{pooled}} \quad (1)$$

Where:

d	= Cohen's Effect size
$\overline{X_e}$	= mean of the experimental group
$\overline{X_c}$	= mean of the control group
SD_{pooled}	= Pooled standard deviation

2.2 Pooled standard deviation

The following equation calculates the pooled standard deviation (SD_{pooled}).

$$SD_{pooled} = \sqrt{\frac{(N_e - 1)SD_e^2 + (N_c - 1)SD_c^2}{(N_e + N_c - 2)}} \quad (2)$$

Where:

SD_{pooled} = Pooled standard deviation
N_e = Sample size of the experimental group
SD_e = Standard deviation of the experimental group
N_c = Sample size of the control group
SD_c = Standard deviation of the control group

After calculating the effect size using the formula, the effect size can be categorized using Cohen's effect size criteria, as shown in Table 3.

Table 3. Effect size criteria

Effect Size	Interpretation
$0 \leq d < 0,2$	Small effect
$0,2 \leq d < 0,8$	Medium effect
$d \geq 0,8$	Large effect

3. RESULT AND DISCUSSION

This study analyzed 16 articles that studied the effects of problem-based learning on scientific literacy, as shown in Table 4 below.

Table 4. List of Articles that Meet the Criteria

Article Code	Year	Title	Authors
J1	2020	Enhancing Science Literacy Through Problem-Based Learning on Global Warming Concepts	Fathiah Alatas, Laili Fauziah
J2	2020	Impact of Problem-Based Learning on Critical Thinking and Science Literacy	Suhirman, Husnul Khotimah
J3	2021	Enhancing Science Literacy Through Blended Learning-Based Problem-Based Learning	Kurniawati, Nur Hidayah
J4	2021	Examining Science Literacy and Adversity Quotient in Problem-Based Learning with Performance Assessment	Aliyana, Sigit Saptono, Budiyono
J5	2022	Impact of Problem-Based Learning Model on Students' Scientific Literacy Skills	Greydio Raidel Lendeon, Cosmas Poluakan
J6	2022	Blended Learning-Based Problem-Based Learning and Its Influence on Student Science Literacy at MTsN 1 South Bengkulu	M. Arifky Pratama, Razi Zilhakim
J7	2022	Comparing Student Science Literacy in Problem-Based Learning and Project-Based Learning Approaches	Mazidah Qurrotu Aini
J8	2022	Effectiveness of Interactive Video-Assisted Problem-Based Learning in Enhancing Elementary School Students' Science Literacy	Agesti Purnaning Putri, Sigit Saptono, Udi Utomo
J9	2023	Impact of the Problem-Based Learning Model on Science Literacy Skills of Eleventh-Grade MIA Students at SMA Angkasa Maros	A. Annisa Tri Utami Yusuf, Halimah Husain, Sumiati Side
J10	2023	The Impact of Problem-Based Learning Science Educational Media on Students' Science Literacy Skills	Awalina Barokah, Ira Restu Kurnia, Umi Kalsum
J11	2023	Enhancing Student Science Literacy through the Implementation of the Problem-Based Learning Model with Popular Articles at SMA Negeri 1 Mamasa	Jirana, Syamsiara Nur, Mesra Damayanti, Agus Siswanto Wijaya
J12	2023	The Influence of the Problem-Based Learning Model on High School Students' Science Literacy	Ety Kurniati, Kadek Ayu Cintya Adelia
J13	2023	Effect of Ethnoscience-Based Problem-Based Learning on Elementary School Students' Science Literacy Skills	Ilmiatul hidayanti, Fitria Wulandari
J14	2023	The Impact of the Problem-Based Learning Model on Science Literacy Skills of Fifth-Grade Students in Science Education	Safira Dwi Ariana, Hafiziani Eka Putri, Puji Rahayu
J15	2023	Problem-Based Learning Model and Cognitive Style in Developing Science Literacy Among Fifth-Grade Elementary School Students	Ni Kadek Dewi Anggreni, I Gede Margunayasa, I Nyoman Laba Jayanta

Article Code	Year	Title	Authors
J16	2024	The Effectiveness of Problem-Based Learning Media Using Edugames to Enhance Science Literacy and Collaboration in Solar System Learning	Sumarsih, Parmin, Lusi Rachmiazasi Masduki

The effect size of each study was determined using Cohen's d formula. Cohen's d is utilized to determine the mean difference between pretest and posttest while accounting for the standard deviation of each study. A subsequent analysis was undertaken to determine the most significant impact of PBL on science literacy. The research results were categorized according to the variables that impact effect size. The classification of effect sizes from the analyzed articles is presented in Table 5 below.

Table 5. Effect size by category

Article Code	ES	$\overline{ES}$	Category	N Artikel
J13	0,22	0,22	Small	1
J8	0,48	0,65	Medium	4
J10	0,68			
J3	0,72			
J6	0,73			
J5	0,86	2,24	Large	11
J14	0,89			
J2	0,97			
J16	1,09			
J4	1,26			
J9	1,57			
J1	2,61			
J15	3,03			
J12	3,13			
J7	4,30			
J11	4,92			
$\overline{ES}$		**1,72**	**Large**	**16**

According to Table 5, data analysis from 16 articles showed an average overall effect size of 1.72, which qualifies for the large category. There were eleven articles with a large effect size, four with a medium effect size, and one with a small effect size. These findings demonstrate that implementing PBL has a significant effect on enhancing student science literacy. This result aligns with the study conducted by Alatas & Fauziah (2020), which reported that PBL positively influences the improvement of students' science literacy, particularly in fostering their ability to explain scientific phenomena and design scientific investigations.

While the overall implementation of PBL has proven effective, the varied distribution of effect sizes indicates that specific factors can influence the research outcomes. As a result, a further analysis was performed to analyze the impact of research location, educational level, subject matter, and implementation aspects on PBL's effectiveness in promoting student science literacy.

Table 6. Correlation of Effect Size and Research Location

Location	N Article	$\overline{ES}$	Category
City	5	1,88	Large
District	10	1,76	Large
Unknown	1	0,48	Medium

According to Table 6, PBL's impact on science literacy among students is not significantly different across research locations. Cities have an average effect size of 1.88, while districts have an average of 1.76, both considered significant. This indicates the implementation of PBL is similarly advantageous in both locations, with no significant differences in effects on student science literacy. These findings are aligned with those observed by Kurniawati et al. (2023) and Samritin (2023), who discovered that the research location had no significant impact on the effectiveness of PBL in promoting science literacy. In these studies, PBL consistently produced significant effect sizes across multiple locations, indicating that the effectiveness of this learning model is determined by implementation characteristics rather than the research location itself.

One article with an unknown location had an average effect size of 0.48, which is considered medium. Although this article does not name a specific place, the study was conducted in a primary school. As a result, the reduced effect size is not due to geographic location but rather to other factors, such as the educational level at which the research occurred.

In addition to the geographical variable, the educational level was examined in this study to determine its impact on effect size. Table 7 provides a more complete explanation of this variable.

Table 7. Correlation of Effect Size and Educational Level

Educational Level	N Artikel	$\overline{ES}$	Category
Elementary School	7	0,48	Medium
Junior High School	3	0,77	Medium
Senior High School	6	1,95	Large

According to Table 7, the implementation of PBL has a significant influence at the senior high school level, with an average effect size of 1.95. In contrast, the implementation at the junior high and elementary school levels falls within the moderate range, with average effect sizes of 0.77 for junior high and 0.48 for elementary school. PBL has a more significant impact at the senior high school level than at the junior high and elementary levels. This is related to the higher cognitive development of high school students. This growth allows students to think critically, logically, and abstractly and have a more comprehensive learning experience (Addzaky, 2024). High school students demonstrate greater independence in managing the problem-based learning process and may actively participate in group projects, which maximizes the benefits of PBL. Conversely, at the elementary and junior high levels, the impact of PBL is more limited because students are still developing critical and collaborative thinking skills central to PBL (Fajeri et al., 2024).

The effect size analysis results from the subject matter perspective are presented in Table 8 below.

Table 8. Correlation between Effect Size and Subject Matter

Subjects	N Article	$\overline{ES}$	Category
Global Warming	1	2,61	Large
Dynamic Fluids	1	0,68	Medium
Temperature, Heat, and Its Transfer	2	2,70	Large
Forces and Motion	1	0,22	Small
Environmental Pollution	1	0,86	Large
Solar System	1	3,03	Large
Science	9	1,61	Large

According to Table 8, applying PBL to improve student science literacy considerably impacts science and physics subjects such as global warming, temperature, heat transfer, environmental pollution, and the solar system. These findings suggest that PBL effectively improves students' conceptual comprehension of these topics. Meanwhile, the topic of Dynamic Fluids had a moderate effect size, while Forces and Motion had a negligible effect. Thus, it is clear that the significance of the effect size created by the application of PBL varies with the subject matter studied. This difference is further influenced by the type of learning intervention used.

The correlation between effect size and type of learning intervention in PBL varies depending on the methodologies used. The factors involved in implementing PBL using certain media or instructional methods substantially impact learning effectiveness, as shown in Table 9.

Table 9. Correlation between Effect Size and Factors Involved

Factors Involved	N Article	$\overline{ES}$	Category
PBL and Learning Media	2	1,76	Large
PBL and Teaching Techniques	4	1,68	Large
PBL without Media and Teaching Techniques	10	1,72	Large

According to Table 9, which highlights the significant effect of implementing PBL on improving student science literacy in physics education, the data indicate that using appropriate learning material and teaching strategies can significantly enhance the effectiveness of PBL. This is demonstrated by the large effect sizes found for each evaluated intervention.

The most substantial effect sizes were noted in research integrating PBL with educational media. Proper utilization of these media enhances PBL by facilitating more precise visualizations, fostering dynamic student-material interactions, and deepening learners' comprehension. Educational games (edugames), which blend gaming elements with educational content, have been identified as particularly effective in this context. Sumarsih (2024) reports that combining PBL with edugames significantly boosts science literacy among students by encouraging active participation and simplifying the comprehension of complex topics, such as the Solar System. This finding is supported by Barokah et al. (2023), who demonstrated that PBL strategies employing learning media markedly enhance students' science literacy.

Media utilization within a PBL framework assists students in addressing authentic, real-world challenges. This method further improves their grasp of scientific concepts, as evidenced by significant improvements in science literacy scores noted by Barokah et al. (2023). Further, Nurhidayah & Suwarna (2024) have found that integrating virtual reality media within a PBL context, particularly on topics such as the Solar System, substantially boosts student science literacy. This approach offers an immersive learning experience that fosters a deeper comprehension of the subject matter.

Empirical evidence indicates that PBL profoundly influences student science literacy at various educational stages. For instance, the GlobalEd 2 (GE2) intervention with a PBL approach significantly improved social science literacy and the ability to conduct scientific inquiries among high school students (Lawless et al., 2018). Additionally, combining PBL with a flipped classroom model has improved comprehension of chemical reaction kinetics, especially in students with advanced critical thinking capabilities (Paristiowati et al., 2019).

Incorporating multimedia technologies also positively enhances the implementation of PBL. For instance, using media like Prezi has been proven to support enhancements in science literacy and independent learning in elementary students (Kristiantari et al., 2022). Furthermore, approaches incorporating social science issues into PBL help students apply their scientific knowledge in real-world contexts, enabling them to make more accurate decisions and understand scientific phenomena deeply (Rubini et al., 2019). The development of critical thinking abilities represents another significant function of PBL. Classroom action research demonstrates that PBL elevates science literacy and enhances critical thinking skills through innovative pedagogical strategies that promote higher-order thinking (Biruni et al., 2023). Notably, the positive impact of PBL extends to students from economically disadvantaged backgrounds, who exhibit marked improvements in scientific knowledge and problem-solving skills (Liu et al., 2021).

This study underscores that integrating learning media, such as interactive simulations or edugames, alongside problem-based learning (PBL) enriches students' educational experiences and aids in their understanding of intricate physics concepts. Through PBL, students are equipped with essential problem-solving skills crucial for science literacy. Engaging with this educational approach, students not only acquire theoretical knowledge in physics but also develop crucial critical, analytical, and collaborative thinking skills necessary for navigating real-life physical phenomena. Consequently, the research supports this method as an efficacious way to enhance science literacy, particularly within physics education.

4. CONCLUSION

Applying Problem-Based Learning (PBL) in physics education has significantly enhanced student science literacy. Analytical results indicate that PBL substantially influences science literacy, with an average effect size of 1.72, classified as significant. The variability in effect size depends on factors such as educational level, subject matter, and implementation strategies. At the academic level, PBL significantly impacts senior high schools (effect size 1.95), while elementary and junior high schools show a medium effect size. Regarding subject matter, PBL is highly effective in topics such as Global Warming, Temperature, Heat and Their Transfer, and the Solar System, each showing large effect sizes. Conversely, topics like Forces and Motion exhibit more minor impacts. Implementation variables, including the incorporation of instructional media and pedagogical strategies, significantly contribute to the effectiveness of PBL.

The PBL has been demonstrated to effectively improve students' science literacy, particularly at the senior high school level and in specific subject areas, with greater efficacy when combined with suitable instructional media. However, this study is limited by the number of articles analyzed. It does not account for additional factors that may influence the effectiveness of PBL, such as student engagement and teacher facilitation skills. Therefore, further research is recommended to explore these factors to understand PBL's effectiveness comprehensively. This study also suggests that educators integrate technology and interactive learning media to optimize the application of PBL in physics education and more effectively enhance student science literacy.

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