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Optimizing Scientific Literacy: A Comprehensive Examination of the Effectiveness of Problem-Based Learning

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ABSTRACT
Objective: Able to face global challenges. One approach that has garnered attention is problem-based learning, considered capable of enhancing students' scientific literacy. This article aims to design and analyze the improvement of scientific literacy through problem-based learning methods. **Method**: The method employed in this research is a literature review. **Results**: The analysis revealed that PBL significantly improves students' scientific literacy skills. N-Gain values indicated moderate to high gains, and t-test results showed significance values below 0.05, confirming a substantial increase in scientific literacy after PBL implementation. **Novelty**: This article provides a comprehensive evaluation of Problem-Based Learning (PBL) in enhancing scientific literacy. Analyzing 15 selected studies, it shows significant improvements in students' scientific literacy skills, supported by N-Gain values and t-test results. The review highlights PBL's effectiveness, including the integration of technology, and offers robust evidence of its positive impact on students' ability to understand and apply scientific information, thus enriching the literature on effective teaching strategies.

INTRODUCTION

Knowledge about the world can be obtained through science. As a process, outcome, and institution, science enables individuals to participate in the construction of new knowledge and use information to achieve desired goals (Amelia & Rahmatina, 2019). To access science, both in its use and creation, a sufficient understanding of the activities and practices of science is required, known as scientific literacy (Adiwiguna et al., 2019).

Scientific literacy skills are a manifestation of an individual's ability to investigate, comprehend, and apply scientific information carefully and critically (Putri, 2022). Scientific literacy skills have undeniable relevance in the context of the continuously evolving modern society (Nuzula, 2022). This ability serves as a crucial foundation for individuals to understand, evaluate, and effectively apply scientific information. Scientific literacy is not merely an academic skill but rather a set of skills that support active participation in the dynamics of a society increasingly influenced by scientific and technological advancements.

PISA, an International Student Assessment Program, defines scientific literacy as the mastery of scientific knowledge, the ability to use knowledge to identify new information, explain scientific phenomena, and draw conclusions related to science (Karmila et al., 2021). Currently, the mastery of scientific literacy is considered a necessity for every student in daily life. Scientific literacy plays a crucial role in shaping thinking patterns and behaviors, as well as building individual character to care for and be responsible for oneself, society, the universe, and also face the challenges encountered by a modern society highly dependent on technology. The COVID-19 pandemic has resulted in a decline in scientific literacy skills internationally by 12 points based on the PISA 2022 results, with Indonesia experiencing a decrease of 13 points (Kementerian Pendidikan, 2023).

The low level of scientific literacy skills in Indonesia reflects a discrepancy in the application of teaching methods in science education(Ariana et al., 2023). Various factors contribute to the low level of students' scientific literacy, including the curriculum, teaching methods, model selection, facilities, infrastructure, and more (Kurniawati & Hidayah, 2021). One significant factor influencing the low level of scientific literacy is the determination of teaching methods and models by teachers (Hafizah, 2021; Rubini et al., 2019; Wong et al., 2021). The deficiency in scientific literacy stems from a science learning approach that focuses solely on memorization of material, with the implementation not being comprehensive and integrated.

The issue of low scientific literacy in Indonesia should undoubtedly receive full attention for the optimal improvement of scientific literacy. Scientific literacy can be enhanced through various innovative learning models (Prastika et al., 2019). Effective learning models that improve scientific literacy must meet several specific criteria, including (1) being active and participatory, encouraging students to engage directly in the learning process through discussions, experiments, and science projects; (2) Contextuality and relevance of learning material are crucial, where scientific concepts are explained using case studies or real-life examples related to students' daily lives; (3) effective learning models are also collaborative, fostering cooperation among students and creating an environment that supports the sharing of ideas. Other criteria include a focus on the development of science process skills, with an emphasis on critical thinking, analysis, and experimentation. Integrated and holistic, learning models should connect scientific concepts with other subjects and the context of everyday life; (4) Flexibility and differentiation are needed to accommodate different learning styles and levels of understanding among students. The integrated use of technology is also a crucial criterion, leveraging digital tools to enhance the learning experience. In this regard, teachers play a role as facilitators and guides who support active and reflective learning; (5) learning models need to include continuous formative assessment to understand student progress and provide constructive feedback (Fitria et al., 2022).

One innovative learning model is PBL. PBL is a learning model that emphasizes problem-solving as its main focus (Karimah, 2023). Students are encouraged to actively engage in solving real and relevant problems (Nevrita et al., 2019). The syntax in the PBL learning model includes directing learners to the problem, organizing learners for learning, facilitating independent and group investigations, developing and presenting artifacts and exhibitions, as well as analyzing and evaluating the problem-solving process (Arends, 2009). Based on the presented syntax and correlation with criteria for learning models that can enhance scientific literacy, PBL should be considered an effective model in improving scientific literacy.

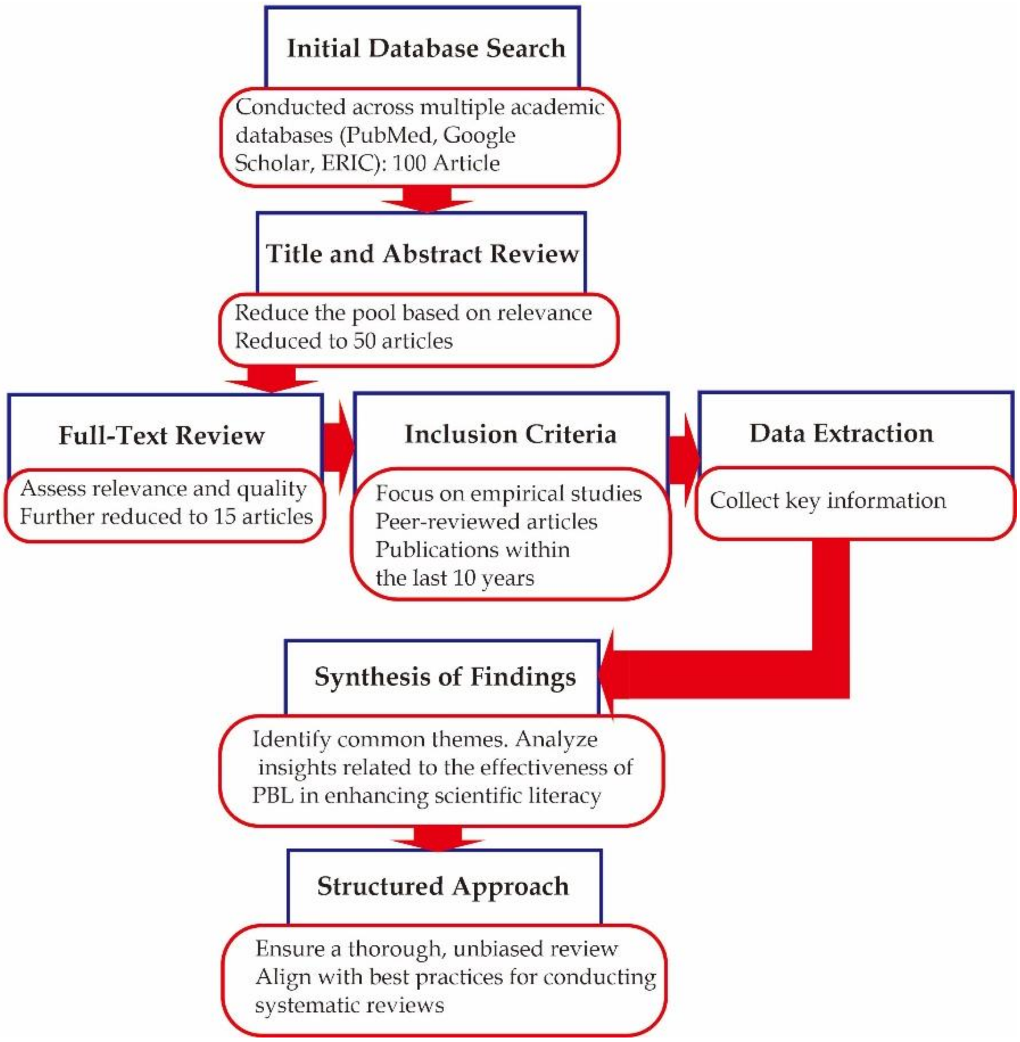
The purpose of this research is to thoroughly investigate and present a comprehensive understanding of the effectiveness of PBL in enhancing scientific literacy. The novelty of this study lies in its comprehensive analysis of recent research, incorporating the integration of technology in PBL and its multidimensional impact on scientific literacy. The objective is to explore various aspects related to the implementation of PBL in the context of science education, including its impact on student motivation and overall effectiveness. The research questions guiding this study are: How does PBL influence students' scientific literacy? What role does technology play in the effectiveness of PBL?

How do different educational contexts affect the outcomes of PBL implementation? Additionally, this article seeks to contribute to the literature by presenting recent findings from relevant research on the implementation of PBL in improving scientific literacy.

RESEARCH METHOD

The research method applied in this study is a comprehensive literature review, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The PRISMA method enhances the clarity and transparency of the literature review process, ensuring a systematic approach to identifying, screening, and including relevant studies (Scholten et al., 2019). The detailed description of the PRISMA method is presented in Figure 1.

Figure 1. PRISMA method (Adapted from Scholten et al., 2019).



RESULTS AND DISCUSSION

Results

In general, the number of articles reviewed in this research is 50 articles. The data have been analyzed and carefully sifted according to the criteria and limitations related to the learning model and scientific literacy abilities. In this context, 15 articles that meet the criteria and limitations have been identified for this study. The results obtained were then analyzed comprehensively to evaluate the impact of the PBL model on students' scientific literacy abilities. Table 1 are the 15 identified articles, including their titles and publication years, obtained through the search, analysis, and data selection process.

Table 1. Title and year of publication of articles related to the PBL model and scientific literacy skills

Code	Author	Title	Publication Year
A1	Sariningrum et al.,	Pembelajaran Berbasis Masalah (PBL) Dengan Konteks Socioscientific Issues pada Materi Pemanasan Global untuk Meningkatkan Literasi Sains Siswa	2018
A2	Rubini et al.,	Using Socio-scientific Issues in Problem Based Learning to Enhance Science Literacy	2019
A3	Prastika et al.,	The Effectiveness of Problem-Based Learning in Improving Students Scientific Literacy Skills and Scientific Attitudes	2019
A4	Fauziah et al.,	Meningkatkan Literasi Sains Peserta Didik Melalui Pembelajaran Berbasis Masalah Berorientasi Green Chemistry Pada Materi Laju Reaksi	2019
A5	Nasution et al.,	Effectiveness problem-based learning (PBL) with reading infusion strategic to improving scientific literacy for high school students on topic global warming	2019
A6	Khotimah et al.,	The Effects of Problem-Based Learning on Critical Thinking Skills and Student Science Literacy	2020
A7	Karmila et al.,	The Effectiveness of Problem Based Learning (PBL) Assisted Google Classroom to Scientific Literacy in Physics Learning	2021
A8	Lendeon et al.,	Pengaruh Model Problem Based Learning (PBL) Terhadap Kemampuan Literasi Sains Siswa	2021
A9	Nuzula et al.,	Pendidikan Sains Penerapan Model Problem-Based Learning untuk Meningkatkan Kemampuan Literasi Sains Siswa SMP pada Pembelajaran IPA	2022
A10	Aini et al.,	Perbedaan Literasi Sains Siswa dalam Implementasi Model Pembelajaran Problem-Based Learning dan Project-Based Learning	2022
A11	Hidayanti et al.,	The Effect of Problem-Based Learning Based Ethnoscience on Science Literacy Ability of Elementary School	2023
A12	Sholihah et al.,	The Effectiveness of STEM Integrated Problem-Based Learning in Enhancing Student Science Literacy on Temperature and Heat Materials	2023

Code	Author	Title	Publication Year
A13	Asda et al.,	Development of Buffer Solution Students' Worksheet Based on Problem Based Learning with Ethnochemistry to Improve Students' Science Literacy Ability	2023
A14	Dewanti et al.,	Analisis Literasi Sains Siswa SMP pada Pembelajaran IPA dengan Model Problem Based Learning disertai Mind Mapping	2023
A15	Ariana et al.,	Pengaruh Model Problem Based Learning (PBL) terhadap Kemampuan Literasi Sains Siswa dalam Pembelajaran IPA di Kelas V SD	2023

The results obtained from the analysis of 15 articles show that the PBL learning model can improve students' scientific literacy skills. The resulting N-Gain values are presented in Figure 2. Overall research shows that there is a significant difference in students' scientific literacy abilities before and after carrying out learning using the PBL model. N-Gain value greater than 0.70 indicates a high level of improvement, between 0.30 and 0.70 denotes a moderate level of improvement, and 0.30 or less signifies a low level of improvement.

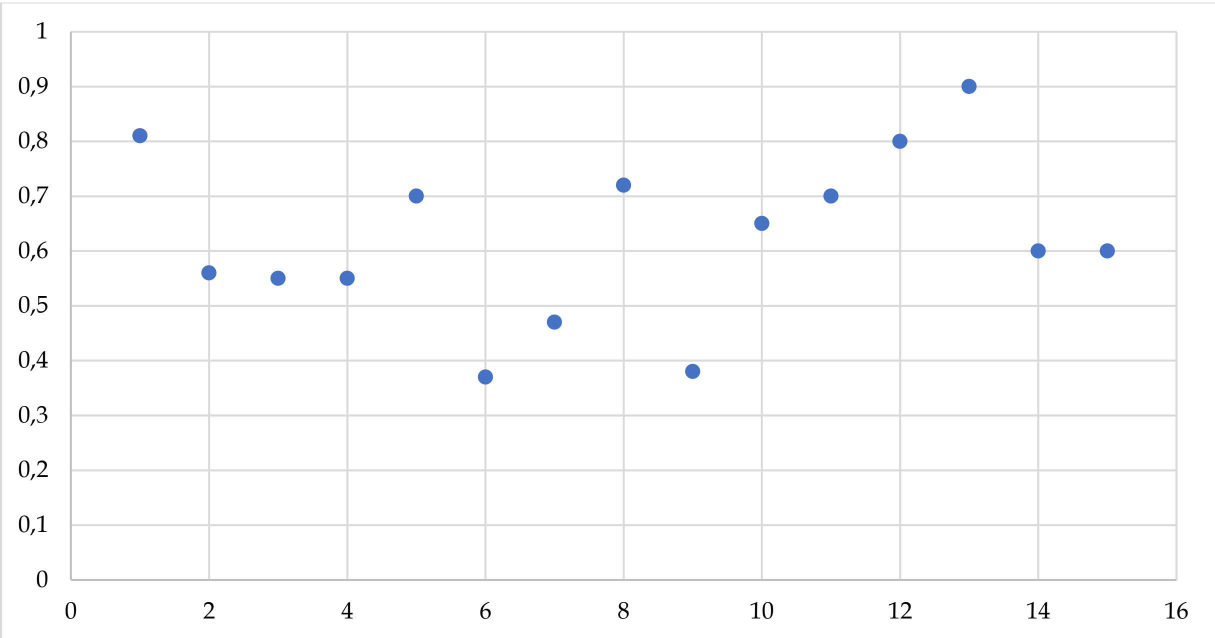


Figure 2. N-Gain result.

Discussion

N-Gain is a measure of the relativity of increasing student understanding or skills after a lesson. The N-Gain value obtained shows significant results regarding the influence of the PBL model on students' scientific literacy skills. Increasing students' scientific literacy skills is included in the moderate to high N-Gain category (Hariyono et al., 2024).

Data in each study were analyzed using the t-test to assess significance. Overall research shows t-test results with a significance value of less than 0.05. Based on the significance value, it can be seen that there is a significant difference between students' scientific literacy abilities before and after learning using the PBL model. Research in previous years also stated that the application of the PBL model had a significant effect on students' scientific literacy skills (Hartatik, 2022).

The indicators of scientific literacy skills to be achieved must be integrated with the syntax of the PBL model. Knowledge about scientific literacy needs to be conveyed through group learning, so that students have the ability to recognize inaccurate information. Researchers from 15 articles used varying methods in implementing the PBL model. Research A1 and A2, presents the context of socioscientific issues, such as global warming, as a basis for implementing PBL, providing a contextual dimension that is relevant to contemporary social and scientific challenges. In addition, research such as A4 focuses on a green chemistry orientation, exploring PBL for reaction rate materials with a sustainable approach. A5 adds the dimension of reading strategies in the implementation of PBL to increase scientific literacy, especially on the topic of global warming. Meanwhile, A7 focused attention on the effectiveness of PBL supported by Google Classroom in increasing scientific literacy, especially in physics learning. Several studies, such as A6, A12, and A13, emphasize the integration of PBL with STEM to enrich learning experiences and increase students' scientific literacy. Research A8 and A15 specifically explored the influence of the PBL model on students' scientific literacy abilities, providing a focus on evaluating the impact of the PBL model in the context of science learning. Meanwhile, research A11 and A13 take an ethnoscience and ethnochemistry-based approach, considering students' local wisdom and culture in science learning. Finally, A14 used scientific literacy analysis with PBL accompanied by mind mapping techniques as a visualization effort to increase understanding of scientific concepts. Through this variety of methods, these studies provide various contributions to students' understanding and scientific literacy, demonstrate the flexibility and adaptability of PBL in various contexts and learning objectives and stimulate the formation of relationships between the knowledge possessed by students and its application in everyday life situations (Ariana et al., 2023; Karimah, 2023; Khotimah, 2020; Nasution et al., 2019; Rubini et al., 2019).

Based on the results of the analysis, it is known that the effectiveness of implementing the PBL model to increase scientific literacy can be influenced by a number of variables. Teacher support is a key factor, where the teacher's ability to design, support and facilitate PBL activities plays a central role. Available resources, including laboratory equipment, scientific literature, and technology, can also influence the success of PBL (Dewanti et al., 2022). Student involvement in PBL activities, collaboration between students, and the relevance of content to real life also play an important role (Asda et al., 2023). A good evaluation system, constructive feedback, and school infrastructure readiness also have a significant impact (Sholihah et al., 2023). A learning culture that encourages exploration, creativity, and problem solving can provide more support for the PBL model. Apart from that, students' abilities in managing projects, completing assignments, and thinking critically are important considerations (Hidayanti, 2023). The complex interactions between these variables emphasize that the effectiveness of PBL is highly dependent on the specific context of a school or classroom. PBL is a learning approach that can significantly increase students' scientific literacy through various integrated syntax elements (Aini, 2022). Presenting contextual problems is key in designing PBL. The problems presented should reflect real-world situations and have a strong scientific context to motivate students to explore scientific concepts in depth. This involves selecting problems that are relevant to everyday life or contemporary scientific issues.

Guiding questions form the basis of the scientific inquiry process. The questions should be designed in such a way as to encourage students to observe, experiment and think critically. This process stimulates a deep understanding of scientific concepts and scientific skills. In addition, collaborative group work is an important aspect of PBL. Collaboration allows students to exchange ideas, share knowledge, and jointly find solutions to given problems. This reflects collaborative practices in science that often involve scientific teams.

Searching for information resources is the next step in building scientific literacy. Students are taught to search for and evaluate relevant resources, including scientific literature, previous experiments, and empirical data. This ability provides the basis for understanding scientific concepts more broadly and deeply (Lendeon, 2022). The process of solving scientific problems is the next step, which includes hypothesis formulation, experimental design, data collection, and analysis of results. This strengthens students' scientific thinking skills and hones their ability to apply scientific methods.

The presentation phase and effective communication are inseparable elements of scientific literacy. Students are taught to present their findings clearly and convincingly, both orally and in writing (Tawfik et al., 2021). This ability to communicate is essential in science, where sharing knowledge with the scientific community is an important step. Reflection and metacognition are also emphasized in PBL, inviting students to reflect on their learning process, evaluate understanding, and plan steps for further development. This includes metacognitive aspects of scientific literacy that strengthen self-understanding of how they learn.

Continuous formative assessment throughout the PBL process is an important support for scientific literacy. The feedback provided helps students understand their strengths and weaknesses, and provides direction for improvement. Finally, the integration of PBL with the overall science curriculum helps students relate learned concepts to previous information, forming a solid and integrated understanding. By combining all these elements, PBL syntax can form a deep learning experience, stimulate curiosity, and build students' scientific literacy holistically (Lestari et al., 2020). The correlation between PBL syntax and the scientific literacy indicators that can be achieved is presented in Table 3.

Tabel 3. Correlation of PBL syntax with indicators of scientific literacy that can be achieved.

PBL Model Syntax (Arends, 2009)	**Achievable Scientific Literacy Indicators** (OECD, 2009)
Phase 1 Directing students to the problem	Recognize problems that may be scientifically investigated
Phase 2 Organizing students to learn	• Identify keywords to search for scientific information • Recognize the main characteristics of scientific inquiry
Phase 3 Assists with independent and group investigations	Applying science to specific situations
Phase 4 Develop and present artifacts and exhibits	• Interpret scientific evidence and create and communicate conclusions

PBL Model Syntax (Arends, 2009)	**Achievable Scientific Literacy Indicators** (OECD, 2009)
Phase 5 Analyze and evaluate the problem solving process	• Identify assumptions, evidence, and reasoning behind conclusions • Reflect on the social implications of scientific and technological developments. • Describe or interpret phenomena scientifically and predict their changes. • Identify appropriate descriptions, explanations, and predictions.

Merdeka Curriculum is a curriculum concept that provides freedom and flexibility to schools to develop the curriculum according to the needs, potential and context of the local community. PBL is one of the learning models that is highly recommended in the Kurriculum Merdeka (Anggraena et al., 2022). PBL promotes a problem-based learning approach, where students are invited to overcome real-world challenges or problems through exploration, collaboration, and problem solving.

PBL is in accordance with the principles of the Merdeka Curriculum because it gives teachers and students the freedom to determine learning problems or projects that are relevant to local realities and student needs. PBL not only focuses on knowledge transfer, but also develops critical thinking, creativity and collaboration skills, which is consistent with the Merdeka Curriculum's goal of creating holistic learning (Hartatik, 2022).

PBL stands out as an educational approach that transcends traditional knowledge transfer methodologies. While conventional teaching often emphasizes the mere transmission of information, PBL delves deeper, fostering critical thinking, creativity, and collaboration skills among students (Setiyaningsih, 2023). This approach aligns seamlessly with the objectives of the Merdeka Curriculum, which seeks to cultivate a holistic learning environment. By prioritizing not only the acquisition of knowledge but also the development of essential cognitive and interpersonal skills, PBL aims to equip students with the tools necessary for success in a rapidly evolving and interconnected world. The emphasis on critical thinking within the PBL framework encourages students to analyze and evaluate information independently. By presenting authentic problems that require thoughtful solutions, PBL prompts learners to question assumptions, consider various perspectives, and engage in meaningful inquiry. This process not only enhances their problem-solving abilities but also nurtures a mindset geared towards lifelong learning (Setiyaningsih, 2023). In this way, PBL goes beyond rote memorization, empowering students to become active participants in their own education and contributing to the broader goals of the Merdeka Curriculum.

The collaborative aspect of PBL plays a pivotal role in preparing students for the challenges of the future. In a world where teamwork and communication are essential, PBL provides a platform for students to work together, share ideas, and collectively solve complex problems (Meng et al., 2023). This collaborative spirit aligns with the Merdeka Curriculum's emphasis on fostering a sense of independence and responsibility among students (Anggraena et al., 2022). By engaging in collaborative learning experiences, students not only enhance their subject-specific knowledge but also develop interpersonal skills that are crucial for success in their academic journey and beyond.

PBL emerges as a catalyst for fostering adaptability and problem-solving skills among students, attributes that are indispensable in navigating a dynamic and ever-changing world. In the face of complex challenges, PBL empowers learners to develop a proactive mindset, equipping them with the resilience and agility needed to address a variety of issues (Mursyd & Rohman, 2023). This aligns seamlessly with the objectives of the Merdeka Curriculum, which seeks to prepare students for the uncertainties of the future by emphasizing the cultivation of versatile skills beyond rote knowledge.

PBL transforms teachers into facilitators of learning, allowing them to guide and support students as they explore topics or issues of personal interest. This student-driven approach aligns harmoniously with the principles of independence and freedom championed by the Merdeka Curriculum (Sayfullooh et al., 2023). By providing students with the autonomy to choose their learning paths, PBL encourages a sense of ownership over their education, fostering a deeper and more meaningful engagement with the material. The integration of PBL with local culture and wisdom values serves to enrich the educational experience (Setiyaningsih et al., 2023). Students, when utilizing the PBL framework, have the opportunity to identify problems relevant to their communities. This approach allows them to create solutions that are not only effective but also considerate of the cultural and environmental context (Tawfik et al., 2021). By grounding their learning experiences in local issues, PBL establishes a meaningful connection between classroom education and the daily lives of students (Khotimah, 2020). This localized perspective not only enhances the applicability of knowledge but also instills a sense of responsibility for addressing community needs, aligning perfectly with the goals set forth by the Merdeka Curriculum.

Overall, PBL is a learning model that encourages exploration, collaboration and problem solving, in line with the spirit of the Merdeka Curriculum which gives schools the freedom to develop learning that suits local needs and context (Anggraena et al., 2022). PBL not only creates a deep understanding of learning material, but also develops skills and attitudes that are relevant to students' future needs amidst dynamic change.

CONCLUSION

Fundamental Finding : The PBL model has a significant positive impact on increasing students' scientific literacy. The high N-Gain values in most articles indicate that PBL is effective in improving students' understanding and skills in the context of science. **Implication :** PBL can be adopted as an effective learning strategy to increase scientific literacy. Teachers and educational policy makers can integrate PBL elements into the curriculum to provide students with deeper and more contextual learning experiences. **Limitation :** This research involves a limited number of articles and focuses on educational research literature in Indonesia. **Future Research :** It is recommended to conduct research with a larger sample and include international research. Research could also deepen the analysis of the role of teachers as PBL facilitators, explore the impact of PBL at various levels of education, and identify contextual factors that influence the effectiveness of PBL.

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