Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram
http://ojs.ikipmataram.ac.id/index.php/prismasains/index
e-mail: prismasains.pkpsm@gmail.com

October 2026. Vol. 14, No. 4
p-ISSN: 2338-4530
e-ISSN: 2540-7899
pp. 2557-2576

Mapping Problem-Based Learning in Physics Education: A Bibliometric Analysis of Problem Solving and Collaborative Learning

[1]Sherlynggar Anugrah, [1]Wildan Khusni Mubarok, [1]*Habibi, [2]Ardy Widoseno
[1]Department of Physics Education, Universitas Negeri Surabaya, Surabaya, Indonesia
[2]State Senior High School 14 Surabaya, Surabaya, Indonesia

*Corresponding author e-mail: habibi@unesa.ac.id

Received: September 2026; Revised: October 2026; Published: October 2026

Abstract

This study aims to map the development of Problem-Based Learning (PBL) research in physics education, focusing on the relationship and temporal development of problem solving and collaborative learning. A quantitative bibliometric approach was employed using 113 publications retrieved from the Scopus database on October 4, 2026, covering the period 2015–2026. Bibliographic data were analyzed using VOSviewer and Bibliometrix to examine publication trends, citation patterns, scientific collaboration, keyword co-occurrence, and thematic development. Additionally, the five most-cited publications were examined to identify influential research contributions. The findings indicate that PBL research in physics education has experienced fluctuating publication trends, with 22 publications recorded in 2026 as of the data retrieval date. Keyword co-occurrence analysis reveals a conceptual connection between problem solving and collaborative learning, suggesting that cognitive and social dimensions are interconnected within the PBL research landscape. Temporal analysis identifies collaborative skills, collaborative settings, artificial intelligence (AI) literacy, and digital literacy as relatively recent research interests. However, these developments do not provide sufficient evidence of a thematic shift from problem solving toward collaborative learning; rather, they indicate the coexistence and potential expansion of both dimensions. Geographically, Indonesia dominates the research landscape with 66 publications (58.4%). Meanwhile, Physics and Astronomy (30.3%) and Social Sciences (25.3%) represent the leading subject areas. This study highlights the importance of integrating cognitive and social dimensions in PBL research and provides directions for future investigations into collaborative problem solving and technology-supported physics learning.

Keywords: Collaborative learning; Physics education; Problem-based learning; Problem solving; Bibliometric analysis

How to Cite: Anugrah, S., Mubarok, W. K., Habibi, H., & Widoseno, A. (1026). Mapping Problem-Based Learning in Physics Education: A Bibliometric Analysis of Problem Solving and Collaborative Learning. *Prisma Sains: Jurnal Pengkajian Ilmu Dan Pembelajaran Matematika Dan IPA IKIP Mataram*, *14*(4), 2557–2576. https://doi.org/10.33394/j-ps.v14i4.22762

https://doi.org/10.33394/j-ps.v14i4.22762

Copyright© 2026, Anugrah et al.
This is an open-access article under the CC-BY License

INTRODUCTION

Quality education is a fundamental foundation for developing human resources who are competent, competitive, and capable of responding to the demands of the twenty-first century (Dwikoranto et al., 2025; Karoso et al., 2024; W. Mubarok et al., 2026). Education in the 21st century requires students to develop a range of skills, including critical thinking, problem-solving, communication, and collaboration, to address various challenges in everyday life (Suprapto et al., 2024; Xu et al., 2023). Therefore, learning should no longer focus solely on knowledge acquisition but should also provide active and contextual learning experiences that foster higher-order thinking skills (Habibi et al., 2026; Pertiwi, 2019; Sujanem & Putu Suwindra, 2023; Trisnayanti et al., 2023). These demands highlight the importance of instructional approaches that actively engage students in investigating problems, exchanging ideas, and constructing knowledge through meaningful learning activities (Suciati et al., 2024).

Physics is a field of science that examines natural phenomena through scientific concepts and theories, requiring analytical thinking, conceptual reasoning, and mathematical skills (Lintangesukmanjaya et al., 2025; Rachmawati et al., 2024). Physics learning involves interpreting phenomena, applying scientific concepts, and solving problems that often require abstract reasoning and mathematical representation (W. K. Mubarok et al., 2026; Pospiech & Fischer, 2021). However, physics education still faces challenges when learning focuses on formula application and routine problem-solving rather than conceptual understanding and contextual problem-solving (Miller et al., 2026; Musengimana et al., 2025). This highlights the need for instructional models that connect physics concepts with authentic problems and promote active scientific investigation. One relevant approach is Problem-Based Learning (PBL), which begins with authentic and contextual problems, encouraging students to identify problems, investigate information, develop solutions, and evaluate their findings (Husna et al., 2025; Nicholus et al., 2023; Prastawa & Radiyanto, 2024). Previous studies have shown that PBL supports conceptual understanding, critical thinking, and problem-solving skills in physics education (Argaw et al., 2017; Ayu et al., 2024; Dewi & Rahayu, 2024). Thus, problem solving is a fundamental cognitive dimension of PBL research in physics education, as it reflects how students investigate and resolve physics-related problems.

Beyond problem solving, PBL involves social interaction through group discussions, information exchange, and collaborative investigations. In this study, problem solving refers to the cognitive process of identifying problems, analyzing information, developing strategies, and evaluating solutions, while collaborative learning represents a social process in which students exchange ideas, negotiate perspectives, and construct knowledge collectively. Although interconnected within PBL, these are distinct analytical dimensions: problem solving focuses on addressing problems, whereas collaborative learning emphasizes social interaction and knowledge construction. Through collaboration, students exchange information, present arguments, evaluate alternatives, and develop shared understanding (Dhika et al., 2026; Hmelo-Silver et al., 2023; Koriťáková et al., 2023; Wijaya et al., 2024). However, effective collaborative learning depends not only on group activities but also on interaction quality, instructional design, and the teacher's role in facilitating discussions and investigations (Dinil Arifah et al., 2024; Rahmadani et al., 2026). Therefore, examining both dimensions is essential to understanding whether PBL research emphasizes individual problem-solving, collaborative learning, or the simultaneous development of both.

The development of PBL research in physics education has generated diverse research interests, including learning outcomes, conceptual understanding, higher-order thinking skills, problem-solving abilities, and collaborative learning (Chen et al., 2023). Previous studies have increasingly discussed the role of interaction and collaboration in knowledge construction, suggesting that PBL research encompasses both cognitive and social dimensions of learning (Alfidyah, 2025; Hmelo-Silver et al., 2023). However, the growing visibility of collaborative learning does not necessarily indicate that it has replaced problem solving as the central focus of PBL research. The two themes may develop simultaneously, overlap within individual publications, or demonstrate different patterns of prominence across publication periods. Therefore, their relationship and temporal development need to be examined using systematic bibliometric evidence rather than inferred solely from the appearance or interconnectedness of particular keywords.

Bibliometric analysis provides a systematic approach to examining research development and intellectual structures through publication productivity, citation patterns, scientific collaboration, and keyword relationships (Lundberg, 2023; Robledo-Giraldo et al., 2023). By combining performance analysis and science mapping, it identifies prominent research themes, their interrelationships, and their evolution over time (Lyu et al., 2024; Singh et al., 2021). Previous bibliometric studies have explored PBL research in physics education from different perspectives. Dwikoranto et al. (2024), in *Research Trend of PBL and PjBL in Bibliometric Analysis: Implications for a Better Future of Physics Education*, analyzed 89 publications on

Problem-Based Learning and Project-Based Learning, providing an overview of their research trends and development. Similarly, Nurjanah et al. (2024), in *Bibliometric Analysis of Problem Based Learning in Physics Education: A Scopus Based Study (1996–2023)*, examined 58 publications to identify research productivity, citation patterns, scientific collaboration, and keyword trends. Although these studies provide important insights into the broader development of PBL research, the relationship between problem solving and collaborative learning as distinct research themes remains insufficiently explored, particularly regarding their co-occurrence patterns and development across publication periods. Examining whether collaborative learning emerges as a new research emphasis, extends problem-solving-oriented research, or develops alongside problem solving is therefore essential to understanding the conceptual evolution of PBL research in physics education.

Addressing this gap, the present study examines the relationship and temporal development of problem solving and collaborative learning within the broader bibliometric landscape of PBL research in physics education. Unlike previous studies that mainly mapped general publication trends, research productivity, citation patterns, and the development of PBL and PjBL, this study emphasizes the conceptual relationship between these two learning dimensions. Bibliometric analysis is used to examine publication productivity, citation patterns, scientific collaboration, keyword co-occurrence, and temporal keyword development. The novelty lies in integrating performance analysis, keyword co-occurrence mapping, and temporal comparison to investigate the position, connectivity, and relative prominence of problem solving and collaborative learning in PBL research. Specifically, keyword co-occurrence analysis identifies their connections within the research network, while temporal analysis examines changes in their relative prominence across publication periods. Importantly, thematic shifts are not inferred solely from the emergence of keywords, network positions, or overlay colors but require evidence of changes in relative frequency or prevalence over time, considering overall publication growth. This approach provides an evidence-based understanding of whether collaborative learning reflects a shift in research emphasis, an expansion of problem-solving themes, or the parallel development of both dimensions.

Based on these considerations, this study aims to map the development of Problem-Based Learning research in physics education through bibliometric analysis, with particular attention to publication trends, citation patterns, dominant research themes, scientific collaboration, and the relationship between problem solving and collaborative learning. More specifically, this study addresses four research questions:

1. How has PBL research in physics education developed in terms of publication trends and citation patterns during the period 2015–2026?
2. What are the dominant research themes, and how are problem solving and collaborative learning positioned within the keyword co-occurrence network?
3. How have problem solving and collaborative learning developed across publication periods, and does their relative prominence provide evidence of a thematic shift?
4. What patterns of scientific collaboration, geographical contributions, and disciplinary contributions characterize this research field?

By addressing these research questions, this study seeks to provide a more focused understanding of the conceptual and temporal development of PBL research in physics education. The findings are expected to contribute to the bibliometric understanding of how cognitive and social dimensions of learning are represented and interconnected in the research literature. Furthermore, the study is expected to identify research directions and opportunities for future investigations into the integration of problem solving, collaborative learning, and purposeful technology use in physics education.

METHODS

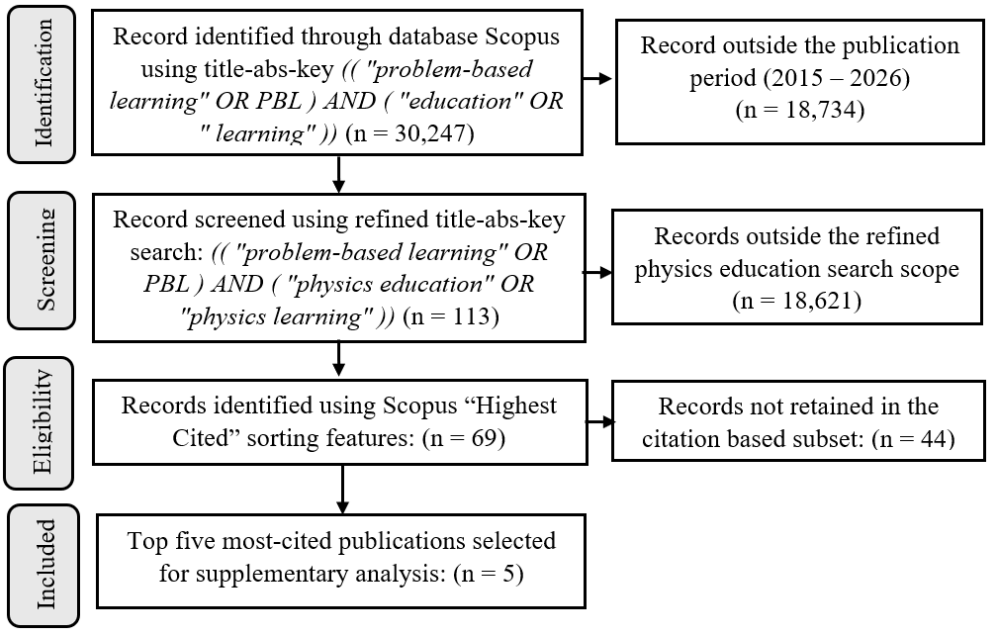
This study employed a quantitative bibliometric research design to examine the development of Problem-Based Learning (PBL) research in physics education. The analysis focused on publication trends, research productivity, citation patterns, scientific collaboration,

and the development of research themes, particularly problem-solving and collaborative learning. Bibliometric analysis enables the systematic evaluation of scientific publications through metadata such as authors, citations, affiliations, and keywords, thereby facilitating the identification of publication trends, research productivity, collaboration networks, and the intellectual structure of a research field.

This study integrated performance analysis and science mapping to provide a comprehensive overview of the development of PBL research in physics education. Performance analysis was employed to examine research productivity and impact, including publication trends, authors, countries, institutions, and publication sources, whereas science mapping was used to visualize relationships among research elements and reveal the conceptual structure of the research field (Lyu et al., 2024; Singh et al., 2021). Bibliographic data were retrieved from the Scopus database on October 4, 2026. Scopus was selected because it provides bibliographic metadata required for publication and citation analyses. The search was conducted using the TITLE-ABS-KEY field, which covers publication titles, abstracts, and keywords.

The literature identification process began with an initial search using the query TITLE-ABS-KEY (("problem-based learning" OR PBL) AND ("education" OR "learning")), which yielded 30,247 records. The results were subsequently restricted to publications from 2015 to 2026, resulting in 18,734 records, while 11,513 records outside the specified publication period were removed. The search was then refined to focus specifically on physics education using the query TITLE-ABS-KEY (("problem-based learning" OR PBL) AND ("physics education" OR "physics learning")). This refinement yielded 113 records, while 18,621 records were outside the refined search scope. These 113 records constituted the final dataset for the main bibliometric analysis.

The literature identification and selection process was presented using the PRISMA framework (Anugrah et al., 2026), as illustrated in Figure 1.



Note: All 113 records were retained for the main bibliometric analysis. The five most-cited publications were selected separately for supplementary analysis

Figure 1. PRISMA for Systematic Literature Review Information Flow

Following the establishment of the main dataset, a supplementary citation-based selection was conducted using the Highest Cited feature available in Scopus. This feature returned 69 records from the initial dataset of 113 publications, while the remaining 44 records were not retained in this citation-based subset. Subsequently, the five publications with the highest citation counts were selected for a more focused examination of influential studies in

PBL research in physics education. It is important to distinguish that all 113 records were retained for the main bibliometric analysis, whereas the five most-cited publications were selected separately for supplementary analysis. Therefore, the citation-based selection did not reduce or replace the main bibliometric dataset. The reduction in records during the publication-year and research-scope refinement stages represents the application of database search restrictions rather than manual exclusion following full-text assessment.

The bibliographic records were exported from Scopus in CSV format and used for subsequent analyses, including publication trends, document types, publication sources, country distribution, scientific collaboration, keyword co-occurrence, and thematic development.

The bibliometric analysis was conducted using VOSviewer and the Bibliometrix package. VOSviewer was used to visualize collaboration networks among authors, institutions, and countries, citation relationships, and keyword co-occurrence (Dang et al., 2025; Dewi & Rahayu, 2024). Meanwhile, the Bibliometrix package was used for descriptive analyses, including annual publication trends, publication source impact, author productivity, and the development of research themes (Khanra et al., 2022). Both tools were applied to the same dataset of 113 publications to maintain consistency across the analyses.

The data analysis comprised several interconnected procedures. First, performance analysis was conducted to identify annual publication trends, document types, publication sources, author productivity, citation patterns, and country distribution. This analysis provided an overview of research productivity and the contributions of different authors, countries, and publication sources to the development of PBL research in physics education. Second, scientific collaboration analysis was performed to examine relationships among authors, institutions, and countries based on their publication records. Third, keyword co-occurrence analysis was conducted to identify dominant research topics and the relationships among keywords within the PBL research landscape in physics education. Particular attention was given to problem solving and collaborative learning as two distinct but potentially interconnected research themes. Their occurrence and interconnections within the keyword network were examined to understand their respective positions and relationships in the research field.

Furthermore, thematic development was examined through the temporal distribution of keywords to identify how research topics were represented across publication periods. Particular attention was given to the development of problem solving and collaborative learning and their relative positions within the research landscape. The temporal keyword visualization was interpreted by considering the average publication year associated with the keywords and their relationships within the network. However, the emergence of a keyword, its network position, or its overlay color alone was not considered sufficient evidence of a thematic shift. Instead, the temporal findings were interpreted cautiously to distinguish between the emergence of newer research topics, the expansion of existing themes, and the possible development of different research emphases over time.

In addition to the main bibliometric analysis, a separate citation-based examination was conducted to identify influential publications. The five publications with the highest citation counts, selected from the 69 records returned by Scopus's Highest Cited feature, were examined in terms of their research focus, findings, and contributions to PBL in physics education. These publications were presented in Table 2 (Overview of Most Cited Papers) to provide further insight into influential research directions and developments in the field. Citation information was based on the Scopus records retrieved on October 4, 2026.

RESULTS AND DISCUSSION

Result

This section presents the results of the bibliometric analysis of Problem-Based Learning (PBL) research in physics education during the period 2015–2026. The analysis focuses on publication trends, document characteristics, geographical distribution, publication sources,

subject areas, scientific collaboration, and keyword co-occurrence patterns. Particular attention is given to the relationship and temporal development of problem solving and collaborative learning as two important dimensions of PBL research. The findings are presented through performance analysis and science mapping to provide an overview of the development, research structure, and emerging directions within the field. Furthermore, the five most-cited publications are examined to highlight influential contributions to PBL research in physics education.

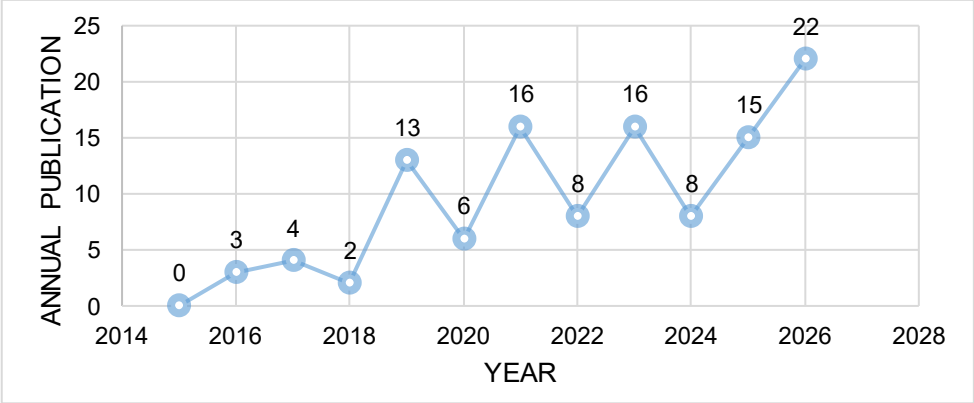


Figure 2. Annual Publication Trends on PBL in Physics Education (2015–2026)

The annual distribution of publications provides an overview of the development of Problem-Based Learning (PBL) research in physics education between 2015 and 2026. As presented in Figure 2, the publication output demonstrates a fluctuating pattern throughout the observation period. No publications were recorded in 2015, followed by three publications in 2016 and four in 2017. The number subsequently declined to two publications in 2018 before increasing considerably to 13 publications in 2019. Publication output then decreased to six publications in 2020 and increased to 16 publications in 2021. A similar fluctuation continued, with eight publications in 2022, rising to 16 in 2023, declining to eight in 2024, and increasing again to 15 publications in 2025. By October 4, 2026, a total of 22 publications had been recorded, representing the highest number observed in the dataset. However, this figure should be interpreted cautiously because the data collection was conducted before the end of 2026 and therefore does not represent a complete annual publication count. Overall, the findings indicate that PBL research in physics education has maintained a recurring publication presence since 2016, although its annual output has varied considerably across the observation period.

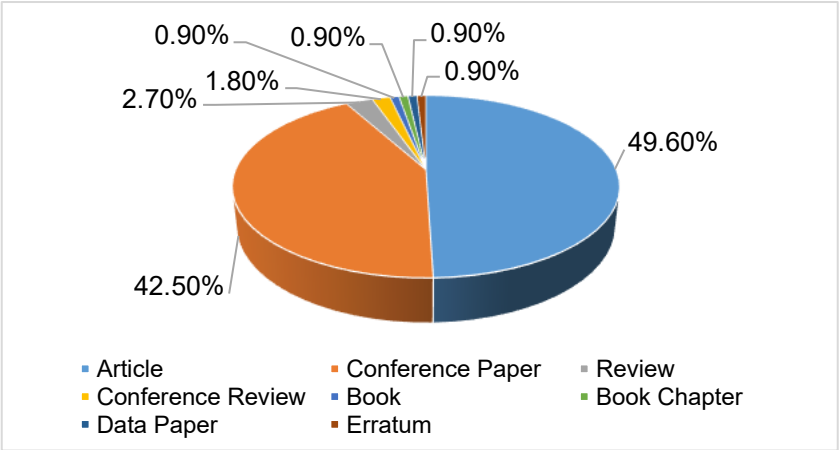


Figure 3. Distribution of Document Types in PBL Research in Physics Education (2015–2026)

The distribution of document types provides an overview of the forms of scholarly publications contributing to PBL research in physics education. As shown in Figure 3, the 113 publications are classified into eight document types, with journal articles representing the largest proportion, accounting for 56 publications (49.56%). Conference papers constitute the

second-largest category, with 48 publications (42.48%). Meanwhile, review articles account for three publications (2.65%), followed by two conference reviews (1.77%). Books, book chapters, data papers, and errata each contribute one publication (0.88%). These findings indicate that journal articles and conference papers collectively account for 104 publications, representing 92.04% of the total dataset. The substantial representation of both document types suggests that research on PBL in physics education is disseminated through journal publications as well as academic conference proceedings. The relatively small number of review articles and other publication types indicates that these formats constitute a smaller proportion of the retrieved literature.

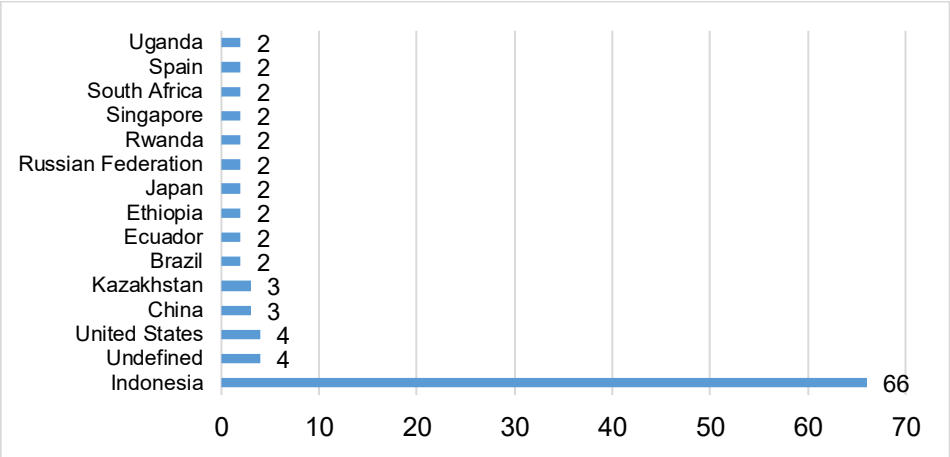


Figure 4. Top Contributing Countries

The geographical distribution of publications provides an overview of the countries contributing to PBL research in physics education. As presented in Figure 4, Indonesia demonstrates the largest contribution, with 66 publications, representing approximately 58.4% of the total dataset of 113 documents. This contribution is considerably higher than that of the United States, which accounts for four publications, followed by China and Kazakhstan with three publications each. Meanwhile, Brazil, Ecuador, Ethiopia, Japan, the Russian Federation, Rwanda, Singapore, South Africa, Spain, and Uganda each contribute two publications. In addition, four records are categorized as undefined due to the absence of identifiable country information in the corresponding affiliation data. The substantial difference between Indonesia and the other contributing countries indicates a considerable geographical concentration of PBL research in physics education within the analyzed dataset. Although several countries have contributed to this research area, their publication outputs remain relatively limited compared with Indonesia**.** This distribution highlights the importance of expanding international research contributions and collaboration to provide broader geographical perspectives on the development of PBL in physics education.

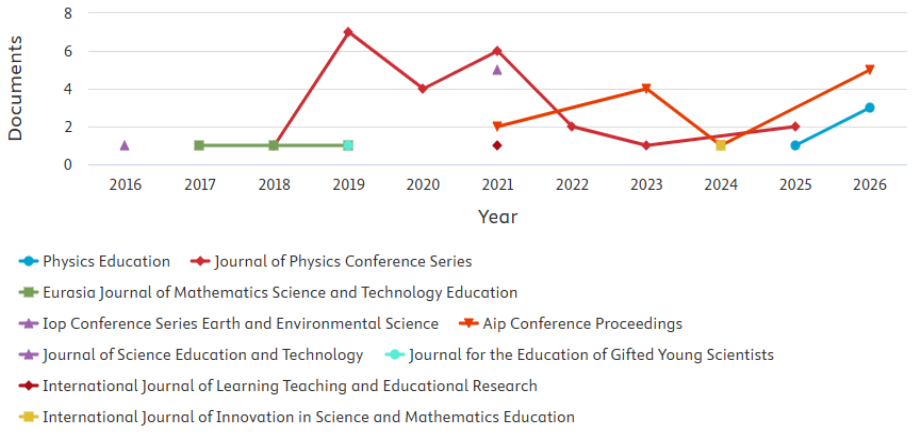


Figure 5. Document per Year by Source

The distribution of publications by source provides further insight into the development and dissemination of PBL research in physics education across different publication outlets. As illustrated in Figure 5, the publication patterns vary among sources throughout the observation period. The Journal of Physics: Conference Series demonstrates the most prominent contribution during the earlier years, reaching its highest output of seven publications in 2019. Its publication output subsequently fluctuated, with four publications in 2020 and six in 2021, before declining to two publications in 2022 and one publication in 2023. In contrast, AIP Conference Proceedings shows a more recent contribution, with publications appearing from 2021 and increasing to four documents in 2023 and five in 2026. Similarly, Physics Education demonstrates a recent increase, from one publication in 2025 to three publications in 2026. Other sources, including Eurasia Journal of Mathematics, Science and Technology Education, Top Conference Series Earth and Environmental Science, Journal of Science Education and Technology, Journal for the Education of Gifted Young Scientists, International Journal of Learning, Teaching and Educational Research, and International Journal of Innovation in Science and Mathematics Education, contribute relatively small numbers of publications across the observation period. Overall, these findings indicate that PBL research in physics education has been disseminated through various publication outlets, particularly conference proceedings and academic journals, with different sources demonstrating distinct patterns of publication activity over time. However, the publication figures for 2026 should be interpreted as provisional because the bibliographic data were retrieved on October 4, 2026, before the end of the publication year..

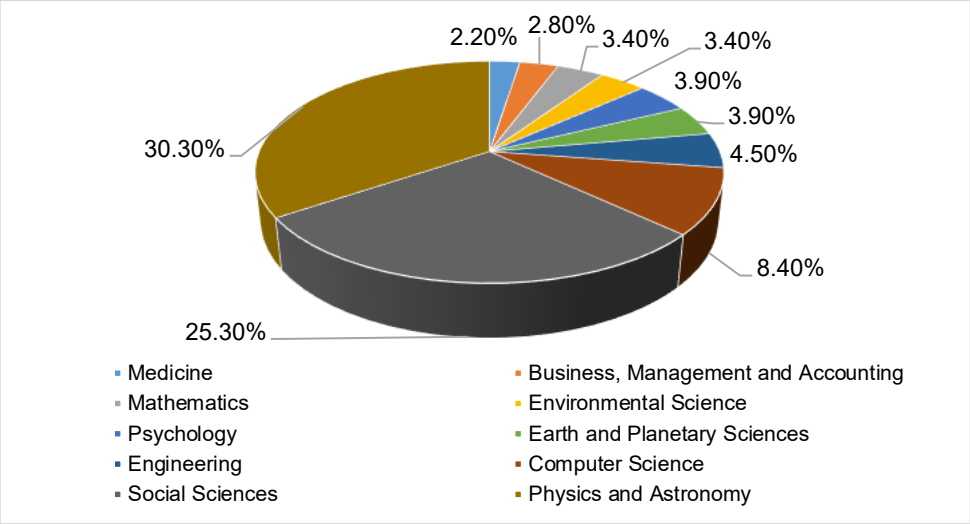


Figure 6. Distribution by Subject Area

The distribution of publications by subject area provides an overview of the disciplinary perspectives contributing to PBL research in physics education. As presented in Figure 6, Physics and Astronomy represents the largest subject area, accounting for 30.3% of the publications, followed by Social Sciences at 25.3%. Computer Science contributes 8.4%, while Engineering accounts for 4.5%. Earth and Planetary Sciences and Psychology each represent 3.9%, followed by Environmental Science and Mathematics at 3.4% each. Business, Management and Accounting contributes 2.8%, while Medicine accounts for 2.2%. Other subject areas collectively represent 11.8% of the publications. The predominance of Physics and Astronomy reflects the central disciplinary context of the analyzed research, while the substantial contribution of Social Sciences highlights the educational and pedagogical dimensions of PBL implementation. Furthermore, the presence of Computer Science, Engineering, Mathematics, and Psychology indicates that PBL research in physics education also intersects with broader disciplinary perspectives related to technology, scientific problem-solving, and learning processes. Overall, the distribution demonstrates the multidisciplinary

character of PBL research in physics education, although its primary contributions remain concentrated in Physics and Astronomy and Social Sciences.

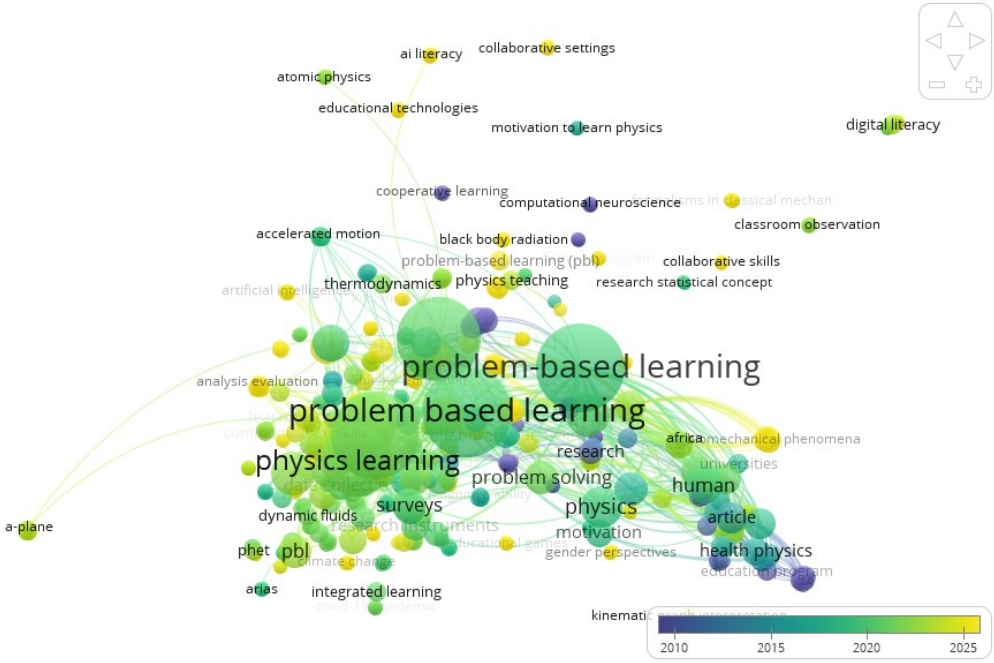


Figure 7. Keyword Co-Occurance Network Visualization

The keyword branch analysis provides further insight into the conceptual relationships among research themes in PBL research in physics education, as illustrated in Figure 7. Several interconnected thematic branches can be identified, particularly those involving problem-based learning, physics learning, problem solving, and physics education. The first branch connects physics learning with problem solving and creative thinking, indicating the relationship between physics learning activities and the development of students' problem-solving and higher-order thinking skills. The second branch illustrates a direct connection between problem solving and collaborative learning, suggesting that these two dimensions are represented within an interconnected research structure. This relationship is particularly relevant because problem solving emphasizes the cognitive processes involved in identifying, analyzing, and resolving problems, whereas collaborative learning focuses on social interaction, idea exchange, and collective knowledge construction. The third branch connects collaborative learning and problem solving with attitude and academic achievement, indicating that research on PBL also addresses students' learning experiences and educational outcomes. In addition, the appearance of specific physics topics, such as dynamic fluids, illustrates the application of PBL across different physics learning contexts.

Taken together, the keyword branches indicate that problem solving and collaborative learning are interconnected research dimensions within the broader conceptual structure of PBL in physics education. The presence of problem solving across several thematic connections suggests its continuing relevance, while its association with collaborative learning demonstrates that research attention also encompasses the social processes involved in learning. However, these network relationships indicate thematic connectivity rather than a chronological transition from one research focus to another. Therefore, the findings are more appropriately interpreted as evidence of the coexistence and potential expansion of cognitive and social dimensions within PBL research, rather than a confirmed shift from problem solving toward collaborative learning.

Table 1. Top 5 Keyword by Author

Keywords	Occurrences	Total Link Strength
Students	40	530
Problem Based Learning	37	490

Keywords	Occurrences	Total Link Strength
Physics Education	29	271
Problem-Based Learning	29	260
Physics Learning	25	251

The most significant keywords are identified based on their total link strength, reflecting the strength of their connections within the research network, with students emerging as the most strongly connected keyword with a total link strength of 530, followed by problem-based learning (490). Physics education and problem-based learning also demonstrate strong connectivity, with total link strengths of 271 and 260, respectively, while physics learning records a total link strength of 251. The high link strength of students indicates its central position within the research network, while the strong connectivity of both problem-based learning and problem-based learning reflects the central role of PBL as the primary research topic. Meanwhile, physics education and physics learning demonstrate strong relationships with the PBL-related keywords, confirming the close connection between PBL and the physics education context. Overall, the keyword network is primarily centered on students, Problem-Based Learning, and physics education, providing a basis for further examination of the thematic branches and keyword relationships within the research domain, as presented in Figure 7.

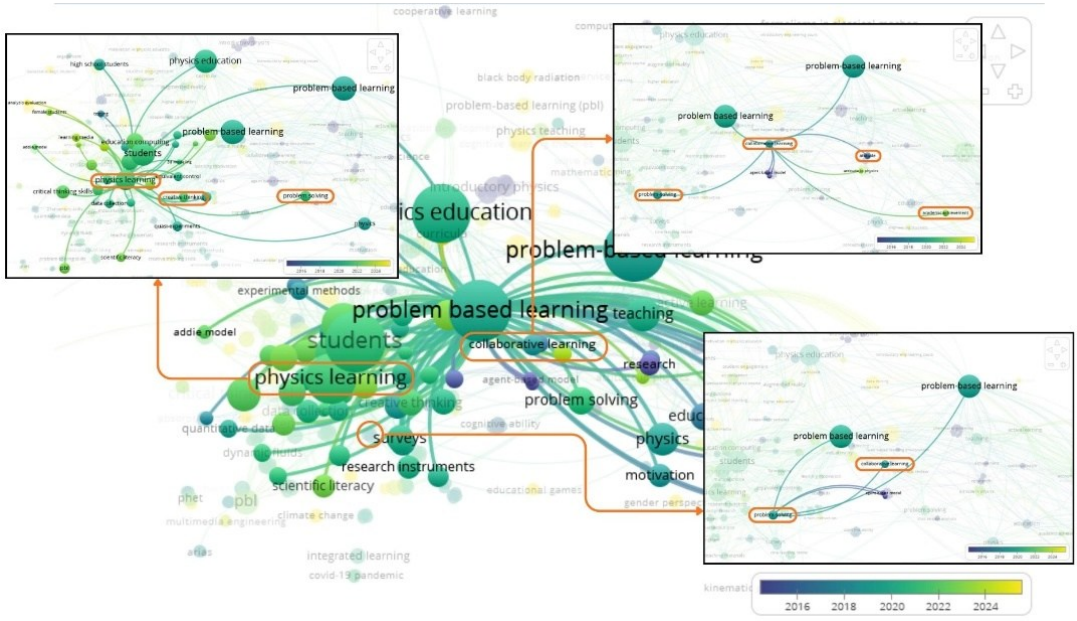


Figure 8. Branches Keywords

The keyword branch analysis reveals several interconnected thematic branches centered on problem-based learning, physics learning, problem solving, and physics education. The first highlighted branch connects physics learning with problem solving and creative thinking, indicating a thematic relationship between PBL-based physics learning and the development of problem-solving and higher-order thinking-related outcomes. The second branch shows a direct connection between problem solving and collaborative learning, demonstrating that both themes occur within the same research network rather than developing as isolated research topics. The third branch further connects collaborative learning and problem solving with attitude and academic achievement, indicating the expansion of PBL research toward learning processes and student outcomes beyond problem-solving performance alone. In addition to these major branches, specific physics topics such as dynamic fluids also appear within the network, showing that PBL research has been applied to different physics learning contexts. The presence of problem solving across multiple branches, together with its connection to collaborative learning, provides evidence of an interconnected thematic development in PBL research in physics education. Overall, the keyword branches illustrate a research landscape

that connects PBL with problem solving as a prominent theme while increasingly incorporating collaborative learning and related student outcomes, supporting the coexistence and potential integration of problem solving and collaborative learning as interconnected cognitive and social dimensions within PBL research.

Table 2. Overview of Most Cited Papers

Author (s)	Citation; SJR	Research Findings and Recommendation
(Fidan & Tuncel, 2019)	407; 4.434 (Q1)	This study investigated the integration of augmented reality into problem-based learning in physics education. The findings indicated that AR-supported PBL could improve students' learning achievement, attitudes, and retention compared with conventional approaches. The study demonstrates the potential of combining technology with PBL to create more engaging and contextualized physics learning experiences. Future research can further examine the integration of AR with PBL across different physics topics and learning contexts.
(Argaw et al., 2016)	147; 0.693 (Q2)	This study investigated the effect of PBL instruction on students' motivation and problem-solving skills in physics using a quasi-experimental design involving 81 grade 12 students. The findings showed a statistically significant difference in problem-solving skills between the experimental and comparison groups, with a positive effect of PBL on students' problem-solving performance. However, the difference in students' motivation to learn physics was not statistically significant. The study highlights the potential of PBL to improve problem-solving skills in physics education, while emphasizing the need for careful implementation to support students' learning motivation.
(Anwar et al., 2019)	95; 0.693 (Q2)	This study compared the ARIAS and PBL learning models in teaching temperature and heat concepts to high school students using a quasi-experimental design. The results revealed a significant difference in students' conceptual mastery between the two learning models, with ARIAS showing greater effectiveness than PBL. The study reported an effect size of 0.45, indicating a medium effect. These findings suggest that the selection of instructional models should consider the specific learning objectives and students' conceptual needs. Further research could explore the implementation of PBL across different physics topics and learning contexts to examine its effectiveness more broadly.
(Lai & Cheong, 2022)	63; 0.884 (Q1)	This review study examines the development and implementation of augmented reality (AR) in education, with particular emphasis on physics education. The study highlights the potential of AR to support virtual laboratories, interactive problem-based learning, visualization, and access to learning resources beyond conventional classroom settings. However, the authors emphasize that existing AR implementations have not yet demonstrated sufficient evidence to conclude that AR has fundamentally transformed physics teaching and learning. Challenges related to pedagogical implementation, educator readiness, technical considerations, and evaluation remain important areas for further research.
(Ceberio et al., 2016)	52; 1.740 (Q1)	This study developed simulation-based teaching materials to improve problem-solving skills in university-level physics. The findings showed that a significant proportion of students

Author (s)	Citation; SJR	Research Findings and Recommendation
		using the simulation-based materials adopted scientific problem-solving procedures, including qualitative analysis, hypothesis formulation, and analysis of results. The experimental group also achieved better results in solving standard textbook problems than students receiving conventional instruction. Most students expressed satisfaction with the simulation-based methodology and showed a favorable attitude toward learning problem-solving. The study suggests that interactive simulations can support the development of systematic problem-solving strategies in physics education.

The analysis of the five most-cited publications provides further insight into influential contributions and research directions in Problem-Based Learning (PBL) research in physics education. As presented in Table 2, Fidan and Tuncel (2019) received the highest number of citations, with 407 citations, followed by Argaw et al. (2016) with 147 citations and Anwar et al. (2019) with 95 citations. Meanwhile, Lai and Cheong (2022) received 63 citations, while Ceberio et al. (2016) received 52 citations. These publications address different aspects of PBL and physics learning, including problem-solving skills, conceptual understanding, technology-supported instruction, and simulation-based learning.

Regarding their research contributions, Fidan and Tuncel (2019) investigated the integration of augmented reality (AR) into PBL and reported improvements in students' learning achievement, attitudes, and retention. Argaw et al. (2016) examined the effects of PBL on students' motivation and problem-solving skills in physics. Their findings indicated a statistically significant improvement in problem-solving skills, although the difference in students' motivation was not statistically significant. In contrast, Anwar et al. (2019) compared the ARIAS and PBL instructional models in teaching temperature and heat concepts and found that ARIAS produced greater conceptual mastery than PBL, with a medium effect size. This finding indicates that the effectiveness of an instructional model may depend on the intended learning outcomes and the characteristics of the subject matter. Meanwhile, Lai and Cheong (2022) reviewed the application of augmented reality in education, particularly its potential to support virtual laboratories, interactive problem-based learning, and visualization in physics education. However, they also highlighted that existing evidence was insufficient to conclude that AR had fundamentally transformed physics teaching and learning. Furthermore, Ceberio et al. (2016) demonstrated that simulation-based teaching materials could support systematic problem-solving procedures, including qualitative analysis, hypothesis formulation, and the interpretation of results**.**

Taken together, these publications highlight the continued importance of problem solving in PBL research in physics education, alongside investigations into technology-supported and simulation-based learning environments. Nevertheless, the findings should be interpreted within the scope of the five selected publications and should not be generalized as representing the entire research field. In particular, the presence of augmented reality and simulation-based studies among highly cited publications indicates their scholarly visibility but does not, by itself, establish a general shift toward technology-enhanced PBL. Similarly, although problem solving is explicitly addressed in several of these studies, the selected publications provide limited direct evidence regarding how collaborative learning is integrated with problem-solving activities. This observation identifies an opportunity for further investigation into the relationship between cognitive processes and social interaction in PBL-based physics learning.

Discussion

The findings demonstrate that Problem-Based Learning (PBL) research in physics education has maintained a consistent presence during the 2015–2026 observation period, although annual publication output fluctuated considerably. Regarding publication productivity, several periods of increased research activity were identified, particularly in 2019,

2021, 2023, and 2025. The 22 publications recorded in 2026 represent the highest number in the dataset; however, this figure should be interpreted cautiously because data collection was conducted on October 4, 2026, before the completion of the publication year. These fluctuations indicate that research interest in PBL has not developed linearly but has remained an active area of investigation. This sustained scholarly attention may be associated with the relevance of PBL to the characteristics of physics education, which requires students to interpret natural phenomena, apply scientific concepts, analyze information, and develop solutions to contextual problems. By presenting authentic problems as the starting point for investigation, PBL provides opportunities for students to engage in scientific inquiry, critical thinking, and problem-solving activities. This interpretation is consistent with previous studies reporting the potential of PBL to improve conceptual understanding, critical thinking, and problem-solving skills in physics education (Ayu et al., 2024; Gumisirizah et al., 2023). Therefore, the publication trend reflects the continuing scholarly relevance of PBL in addressing the cognitive and contextual demands of physics learning rather than demonstrating a continuous increase in research productivity.

Regarding the intellectual development and citation patterns of the field, the five most-cited publications reveal influential contributions addressing problem-solving skills, conceptual understanding, learning outcomes, and technology-supported instruction. Fidan and Tuncel (2019) received the highest citation count, with 407 citations, demonstrating substantial scholarly visibility for research integrating augmented reality (AR) with PBL. Argaw et al. (2016) received 147 citations and contributed empirical evidence concerning the development of physics problem-solving skills through PBL. Meanwhile, Anwar et al. (2019), with 95 citations, provided a comparative perspective by demonstrating that the ARIAS instructional model produced greater conceptual mastery than PBL in teaching temperature and heat. Lai and Cheong (2022) discussed the potential and limitations of augmented reality in educational settings, while Ceberio et al. (2016) demonstrated the contribution of interactive simulations to systematic problem-solving processes in physics. Collectively, these publications indicate that influential contributions to PBL research encompass both established pedagogical concerns, particularly problem solving and conceptual understanding, and the exploration of technology-supported learning environments. However, citation counts represent scholarly visibility rather than direct measures of research quality or instructional effectiveness. Differences in publication years must also be considered because earlier publications have had longer periods to accumulate citations. Consequently, the citation patterns provide insight into influential research contributions without necessarily establishing the relative effectiveness or dominance of particular instructional approaches.

The keyword co-occurrence analysis further identifies the dominant research themes and their conceptual relationships within PBL research in physics education. The prominence of problem-based learning, problem based learning, physics education, physics learning, and students indicates that the research landscape is primarily organized around the instructional model, its disciplinary context, and the learners involved. Among these themes, problem solving occupies an important position through its connections with physics learning, creative thinking, and other learning-related concepts. Collaborative learning and collaborative skills are also connected to the central keyword network, demonstrating that PBL research encompasses social and interactive dimensions in addition to cognitive learning processes. The keyword branch analysis further identifies a direct relationship between problem solving and collaborative learning, with additional connections to attitude and academic achievement. This relationship is theoretically meaningful because problem solving emphasizes the cognitive processes involved in identifying problems, analyzing information, developing strategies, and evaluating solutions, whereas collaborative learning emphasizes interaction, information exchange, negotiation, and collective knowledge construction. These findings are consistent with Hmelo-Silver et al. (2023), who emphasize interaction and knowledge construction in problem-based learning environments, and Koriťáková et al. (2023), who highlight the

importance of collaborative processes in learning. Thus, the findings suggest that problem solving and collaborative learning represent distinct but interconnected dimensions within the conceptual structure of PBL research in physics education.

The temporal keyword analysis provides further insight into how these research themes are positioned across publication periods. Keywords such as problem solving, physics learning, and dynamic fluids appear within relatively earlier-to-middle average publication-year ranges, whereas collaborative skills, collaborative settings, AI literacy, and digital literacy are associated with relatively newer average publication-year ranges. This pattern indicates differences in the temporal positioning of established and relatively recent research topics. In particular, the appearance of collaborative and competency-related keywords suggests that PBL research encompasses broader learning dimensions beyond the investigation of problem-solving outcomes alone. Nevertheless, the temporal positioning of keywords in the overlay visualization does not independently demonstrate an increase in their publication frequency or establish a chronological shift in research emphasis. Therefore, the findings should be interpreted as evidence of thematic development and potential expansion rather than a confirmed transition from problem solving toward collaborative learning. This distinction is important because both themes may develop simultaneously, overlap within individual publications, and contribute to different aspects of PBL implementation. The relationship between problem solving and collaborative learning is consequently better understood as the coexistence and potential integration of cognitive and social dimensions of learning. This interpretation is consistent with Xu et al. (2023), who discuss the contribution of collaborative problem solving to critical thinking, suggesting that problem-solving processes can also be examined through the interaction and shared reasoning involved in collaborative learning.

The relationship between these two dimensions can be further explained through the instructional characteristics of PBL. Students generally engage in group activities to identify problems, exchange information, investigate possible explanations, evaluate alternatives, and develop solutions. These activities require individual cognitive engagement as well as meaningful social interaction. Consequently, the development of problem-solving abilities in PBL cannot be understood solely through individual performance because collaborative processes also provide opportunities for students to articulate ideas, evaluate different perspectives, and construct shared understanding. Hmelo-Silver et al. (2023) emphasize the importance of interaction and knowledge construction in problem-based learning, while Koriťáková et al. (2023) and Wijaya et al. (2024) highlight the contribution of collaborative processes to learning activities. Furthermore, effective collaboration requires appropriate instructional design and teacher facilitation to ensure that group interaction contributes meaningfully to learning objectives (Dinil Arifah et al., 2024; Rahmadani et al., 2026). Accordingly, the connection between problem solving and collaborative learning identified in this study provides a conceptual basis for future investigations into how collaborative interaction can support students' processes of investigating and solving physics-related problems.

The geographical and disciplinary distributions provide additional perspectives on the development of PBL research in physics education. Indonesia represents the largest contribution in the analyzed dataset, with 66 publications, followed by the United States with four publications, while several other countries contribute smaller numbers of publications. This distribution demonstrates a substantial geographical concentration of the retrieved literature in Indonesia. Although contributions from other countries indicate the international presence of PBL research, the differences in publication output highlight opportunities to broaden geographical representation and comparative research. Such comparisons are relevant because educational curricula, classroom practices, teacher preparation, and available learning resources may influence how PBL is implemented across different educational contexts. Regarding disciplinary contributions, Physics and Astronomy represents the largest subject area, accounting for 30.3% of publications, followed by Social Sciences at 25.3%.

Contributions from Computer Science, Engineering, Mathematics, Psychology, and other disciplines further demonstrate the multidisciplinary context of PBL research. The predominance of Physics and Astronomy reflects the disciplinary foundation of the analyzed literature, whereas the substantial contribution of Social Sciences highlights its pedagogical and educational dimensions. The presence of computing and engineering-related research also indicates connections with technological and interdisciplinary learning contexts. However, geographical and subject-area distributions describe the characteristics of the retrieved Scopus dataset and should not be interpreted as direct measures of the quality of PBL implementation or educational outcomes in individual countries.

The geographical and subject-area distributions reveal both opportunities and limitations in the development of PBL research. Indonesia contributes 66 publications, considerably exceeding the contributions of other countries, indicating a strong national contribution but also an uneven international distribution. Differences in curriculum, classroom culture, teacher preparation, and educational resources may influence how PBL and collaborative learning are implemented across contexts, highlighting the need for broader international and comparative research. In addition, although Physics and Astronomy dominates the subject distribution, contributions from Social Sciences, Computer Science, Engineering, Mathematics, and Psychology demonstrate the multidisciplinary character of PBL research. The emergence of AI literacy and digital literacy further indicates potential directions for future research. Overall, the field is moving toward the integration of problem solving, collaborative learning, and technology-supported competencies. However, research that simultaneously integrates these dimensions remains limited. Future studies should therefore examine how collaborative processes can be deliberately designed within PBL to strengthen problem solving across diverse physics topics, educational contexts, and technological environments.

Overall, the findings indicate emerging research interests in the integration of problem solving, collaborative learning, and technology-supported competencies. The principal contribution of this study lies in examining problem solving and collaborative learning as distinct but interconnected research dimensions within the broader PBL research landscape. While problem solving remains an established and prominent theme, its connection with collaborative learning indicates the relevance of examining how cognitive processes and social interaction operate together in physics learning. The relatively newer positioning of collaborative skills, collaborative settings, AI literacy, and digital literacy also suggests opportunities to broaden research attention toward collaborative and competency-oriented learning environments. However, the available bibliometric evidence does not establish that collaborative learning has replaced problem solving or that a statistically verified thematic shift has occurred. Instead, it highlights the possibility of thematic expansion and coexistence, providing a basis for future empirical research examining how PBL can integrate problem-solving activities, collaborative learning, and purposeful technology use across different physics topics and educational contexts.

CONCLUSION

This bibliometric study mapped the development of Problem-Based Learning (PBL) research in physics education from 2015 to 2026, with particular attention to the relationship between problem solving and collaborative learning. The findings indicate that PBL research has continued to expand, with problem solving remaining a central and established research focus. At the same time, the emergence of keywords such as collaborative skills, collaborative settings, AI literacy, and digital literacy indicates a broadening of research interests toward more collaborative, competency-oriented, and technology-supported learning environments.

The keyword co-occurrence and branch analyses identify problem solving as an established research dimension that is conceptually connected to collaborative learning. These findings indicate that cognitive processes and social interactions are interconnected within the broader PBL research landscape. The temporal keyword visualization also reveals differences in the average publication periods of these themes, with collaborative skills, collaborative

settings, AI literacy, and digital literacy appearing among relatively newer research interests. However, the available bibliometric evidence does not establish a confirmed thematic shift from problem solving toward collaborative learning. Instead, the findings suggest the coexistence and potential expansion of research interests toward broader cognitive, social, and competency-related dimensions of PBL.

Regarding geographical and disciplinary contributions, Indonesia represents the largest contributor to the analyzed publication dataset, while Physics and Astronomy and Social Sciences constitute the two most prominent subject areas. Contributions from Computer Science, Engineering, Mathematics, Psychology, and other disciplines further demonstrate the multidisciplinary character of PBL research in physics education. Meanwhile, highly cited publications addressing augmented reality and interactive simulations indicate scholarly interest in technology-supported learning, although citation prominence alone does not establish the effectiveness or dominance of these approaches.

The principal contribution of this study is its focused examination of problem solving and collaborative learning as distinct but interconnected dimensions of PBL research in physics education. By combining performance analysis, keyword co-occurrence mapping, and temporal keyword visualization, this study provides a more focused understanding of their conceptual relationships and temporal positioning within the research landscape. These findings provide a basis for future research to investigate how collaborative learning can be systematically integrated into problem-solving activities through PBL, particularly across different physics topics and educational contexts. Further empirical studies are needed to examine how the quality of collaborative interaction contributes to students' problem-solving performance, conceptual understanding, and other higher-order competencies. Research should also explore purposeful technology integration that supports meaningful investigation, interaction, and knowledge construction rather than treating technology as an independent instructional objective.

RECOMMENDATION

Future research is recommended to move beyond examining the effectiveness of Problem-Based Learning (PBL) primarily in terms of problem-solving outcomes by investigating how collaborative learning and collaborative skills can be systematically integrated into PBL. Researchers should also explore the use of technology-supported PBL, including augmented reality, interactive simulations, and emerging digital technologies, while ensuring that technology serves clear pedagogical purposes rather than functioning only as an additional learning medium. Further studies should examine PBL across a wider range of physics topics, educational levels, and geographical contexts to strengthen the generalizability of existing findings. In addition, empirical studies with rigorous research designs are needed to investigate how collaborative processes within PBL contribute to students' problem-solving performance and other higher-order competencies. Greater international collaboration is also encouraged to address the geographical concentration of publications, particularly the strong contribution from Indonesia. Overall, future research should develop integrated PBL frameworks that connect problem solving, collaborative learning, and purposeful technology integration to support more comprehensive learning outcomes in physics education.

ACKNOWLEDGMENT

The authors would like to express their sincere gratitude to Dr. Habibi, S.Si., M.Pd., as the research supervisor, for his valuable guidance, conceptual input, methodological direction, validation, supervision, formal analysis, and constructive feedback throughout the research and manuscript preparation. The authors also gratefully acknowledge Wildan Khusni Mubarok, S.Pd., for his contributions to the conceptualization, methodology, validation, formal analysis, and critical review of the manuscript. Special appreciation is also extended to Ardy Widoseno, S.Pd., Gr., as a collaborating author, for his contributions to the validation process, investigation, visualization, and review and editing of the manuscript. The authors sincerely appreciate all contributions and support that contributed to the completion of this study.

FUNDING INFORMATION
This research was independently funded by the authors and received no external funding from any public, commercial, or not-for-profit organization.

AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Sherlynggar Anugrah	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	
Wildan Khusni Mubarok	✓	✓		✓	✓					✓				
Habibi	✓	✓		✓	✓		✓			✓		✓		
Ardy Widoseno				✓		✓				✓	✓			

CONFLICT OF INTEREST STATEMENT
The authors declare that they have no competing interests that could have influenced the research, analysis, or publication of this article.

INFORMED CONSENT
Not applicable. This study did not involve human participants, human subjects, or the collection of personal data; therefore, informed consent was not required.

ETHICAL APPROVAL
This study did not involve human participants, animal subjects, clinical procedures, personal data collection, or direct intervention in educational settings. The research was conducted using secondary bibliographic metadata obtained from the Scopus database, including publication titles, authorship information, keywords, citation counts, publication years, and document types. Therefore, ethical approval was not required for this bibliometric study. All data were used solely for academic research, bibliometric mapping, trend analysis, and visualization purposes and were analyzed in accordance with principles of research integrity, transparency, and responsible use of scholarly metadata.

DATA AVAILABILITY
The data used in this study consist of bibliographic metadata retrieved from the Scopus database, including article titles, publication years, author information, institutional affiliations, countries, keywords, citation counts, and document types. The dataset generated and analyzed during this study is available from the corresponding author upon reasonable request. Because the data were obtained from the Scopus database, access to the original records may depend on institutional subscription or database access rights. The processed data used for bibliometric analysis and visualization can be provided for academic verification and research purposes, subject to compliance with relevant database terms and conditions.

REFERENCES

Alfidyah, M. (2025). Penerapan model Problem Based Learning untuk meningkatkan kemampuan berpikir kritis siswa sekolah dasar. *Jurnal Pendidikan Guru Sekolah Dasar Indonesia*, *1*(1), 1-9.

Anugrah, S., Mubarok, W. K., Fitroni, W., & Nisa', K. (2026). Global trends and research directions in technology integration in physics education for SDG 4: a bibliometric analysis (2016-2025). *Journal of Law and Bibliometrics Studies*, *2*(1), 97. https://doi.org/10.63230/jolabis.2.1.97

Anwar, C., Saregar, A., Yuberti, Y., Zellia, N., Widayanti, W., Diani, R., & Wekke, I. S. (2019). Effect size test of Learning model ARIAS and PBL: Concept mastery of temperature and heat on senior high school students. *EURASIA Journal of Mathematics, Science and Technology Education*, *15*(3), em1679. https://doi.org/10.29333/ejmste/103032

Argaw, A. S., Haile, B. B., Ayalew, B. T., & Kuma, S. G. (2017). The effect of problem based learning (PBL) instruction on students' motivation and problem solving skills of physics. *Eurasia Journal of Mathematics, Science and Technology Education*, *13*(3), 857-871. https://doi.org/10.12973/eurasia.2017.00647a

Arifah, D., Nur, K., & Amaliah. (2025). Strategi efektif membimbing diskusi kelompok kecil untuk meningkatkan kolaborasi siswa. *Harmoni Pendidikan: Jurnal Ilmu Pendidikan*, *2*(1), 213–220. https://doi.org/10.62383/hardik.v2i1.1059

Ayu, H. D., Chusniyah, D. A., Kurniawati, M. P., Purwanti, P. F., Lukitawanti, S. D., & Putri, A. N. (2024). Problem-based learning (PBL) as an effective solution to enhance understanding of physics concepts: A systematic literature review. *Journal of Environment and Sustainability Education*, *2*(2), 86–105. https://doi.org/10.62672/joease.v2i2.29

Ceberio, M., Almudí, J. M., & Franco, Á. (2016). Design and application of interactive simulations in problem-solving in university-level physics education. *Journal of Science Education and Technology*, *25*(4), 590-609. https://doi.org/10.1007/s10956-016-9615-7

Chen, H., Tsang, Y. P., & Wu, C. H. (2023). When text mining meets science mapping in the bibliometric analysis: A review and future opportunities. *International Journal of Engineering Business Management*, *15*. https://doi.org/10.1177/18479790231222349

Dang, L. Van, Lyu, H., Matsuura, S., Wagai, R., Yasuno, H., Tanaka, H., & Sugihara, S. (2025). Plant residue quality regulates mineral-associated organic matter formation rate and pathway in converted upland soil. *Environmental Research*, *283*, 122158. https://doi.org/10.1016/j.envres.2025.122158

Dewi, C. A., & Rahayu, S. (2023). Implementation of case-based learning in science education: A systematic review. *Journal of Turkish Science Education*, *20*(4), 729-749. https://doi.org/10.36681/tused.2023.041

Dhika, D. F., Safitrianingrum, A., Farida, N., & Setiadi, H. W. (2026). Pengembangan modul pembelajaran berbasis problem-based learning untuk meningkatkan keterampilan kolaboratif siswa sekolah dasar. *Sosiola Pedagogi: Jurnal Inovasi Pendidikan, Sosial, dan Humaniora*, *2*(1). https://journal.mahsya-educreativa.com/index.php/sosiolapedagogi/article/view/169

Dwikoranto, Dawana, I. R., & Setiani, R. (2024). Research trend of PBL and PjBL in bibliometric analysis: Implications for a better future of Physics education. *Studies in Learning and Teaching*, *5*(2), 296–308. https://doi.org/10.46627/silet.v5i2.359

Dwikoranto, Lintangesukmanjaya, R. T., Astutik, W., Mubarok, W. K., Putra, D. A., Setiani, R., & Bergsma, L. N. (2025). Program evaluation in improving high school physics learning outcomes through an experimental analysis approach. *Journal of Physics: Conference Series*, *3132*(1), 012013. https://doi.org/10.1088/1742-6596/3132/1/012013

Fidan, M., & Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers & Education*, *142*, 103635. https://doi.org/10.1016/j.compedu.2019.103635

Habibi, H., Admoko, S., Herayanti, L., Almaida, N. N., & Anugrah, S. (2026). Contextualizing technology in physics education: Systematic insights into trends, patterns, and gaps (2014–2024). *Multidisciplinary Reviews*, *9*(9), e2026459. https://doi.org/10.31893/multirev.2026459

Hmelo-Silver, C. E., Jeong, H., & McKeown, J. (2023). Synergies among the pillars. In O. Zawacki-Richter & I. Jung (Eds.), Handbook of open, distance and digital education (pp. 1357–1372). Springer. https://doi.org/10.1007/978-981-19-2080-6_83

Husna, A., Ilmi, N., & Gusmaneli, G. (2025). Strategi pembelajaran berbasis masalah dalam meningkatkan kemampuan berpikir kritis peserta didik. *Katalis Pendidikan: Jurnal Ilmu Pendidikan Dan Matematika*, *2*(2), 76-86. https://doi.org/10.62383/katalis.v2i2.1532

Karoso, S., Handayaningrum, W., Handayani, E. W., & Yanuarti, S. (2024). The role of human resource management strategy in creating superior quality educators. *Nidhomul Haq: Jurnal Manajemen Pendidikan Islam*, *9*(3), 596-615. https://doi.org/10.31538/ndhq.v9i3.7

Khanra, S., Kaur, P., Joseph, R. P., Malik, A., & Dhir, A. (2022). A resource-based view of green innovation as a strategic firm resource: Present status and future directions. *Business Strategy and the Environment*, *31*(4), 1395-1413. https://doi.org/10.1002/bse.2961

Koriťáková, E., Jivram, T., Gîlcă-Blanariu, G.-E., Churová, V., Poulton, E., Ciureanu, A. I., Louis, C., Ștefănescu, G., & Schwarz, D. (2023). Comparison of problem-based and team-based learning strategies: A multi-institutional investigation. *Frontiers in Education*, *8*, 1301269. https://doi.org/10.3389/feduc.2023.1301269

Lai, J. W., & Cheong, K. H. (2022). Educational opportunities and challenges in augmented reality: Featuring implementations in physics education. *IEEE Access*, *10*, 43143-43158. https://doi.org/10.1109/ACCESS.2022.3166478

Lintangesukmanjaya, R. T., Mahendra, A., Anugrah, S., Prahani, B. K., Dwikoranto, D., Satriawan, M., & Rizki, I. A. (2024). A EFA analysis of digital technology teaching materials in improving students' critical thinking in physics learning. *JPPS (Jurnal Penelitian Pendidikan Sains)*, *23*-38. https://doi.org/10.26740/jpps.v14n1.p23-38

Lundberg, L. (2023). Bibliometric mining of research directions and trends for big data. *Journal of Big Data*, *10*(1), 112. https://doi.org/10.1186/s40537-023-00793-6

Lyu, H., Matsuura, S., Wagai, R., Yasuno, H., Tanaka, H., & Sugihara, S. (2025). Plant residue quality regulates mineral-associated organic matter formation rate and pathway in converted upland soil. *Environmental Research*, *283*, 122158. https://doi.org/10.1016/j.envres.2025.122158

Miller, K., Miller, O., & Lawrence, G. (2026). Teaching problem solving in undergraduate physics courses: An endorsement for deliberate practice. *Physical Review Physics Education Research*, *22*(2), 020121. https://doi.org/10.1103/7pqt-gd9c

Mubarok, W. K., Anugrah, S., & Citra, N. F. (2026). Mapping augmented reality in Physics education for enhancing students' critical thinking skills: A bibliometric analysis (2015-2026). *SiBET (Studies in Bibliometrics of Education and Technology)*, *1*(2), 1–13. https://scie-journal.net/index.php/SiBET

Mubarok, W., Anugrah, S., & Rizki, I. A. (2026). DEVELOPMENT OF sTEAM-BASED pHYSICS lEARNING KITS AS iNSTRUCTIONAL MEDIA TO iMPROVE HIGH SCHOOL sTUDENTS' cRITICAL tHINKING SKILLS. *INSECTA: Integrative Science Education and Teaching Activity Journal*, *7*(1), 92–104. https://doi.org/10.21154/insecta.v7i1.13723

Musengimana, T., Yadav, L. L., Uwamahoro, J., & Nizeyimana, G. (2025). Instructional strategies for enhancing students' problem-solving skills in physics: a systematic review. *Discover Education*, *4*(1), 380. https://doi.org/10.1007/s44217-025-00733-x

Nicholus, G., Muwonge, C. M., & Joseph, N. (2023). The role of problem-based learning approach in teaching and learning physics: A systematic literature review. *F1000Research*, *12*, 951. https://doi.org/10.12688/f1000research.136339.2

Nurjanah, S., Sultan, J., Aisyah, S., Puspita, D., & Ulyasari, N. (2024). Bibliometric analysis of problem based learning in physics education: A Scopus based study (1996–2023). *Berkala Ilmiah Pendidikan Fisika*, *12*(2), 310–326. https://doi.org/10.20527/bipf.v12i2.18775

Pertiwi, N. P., Saputro, S., Yamtinah, S., & Kamari, A. (2024). Enhancing critical thinking skills through STEM problem-based contextual learning: An integrated e-module education website with virtual experiments. *Journal of Baltic Science Education*, *23*(4), 739–766. https://www.scientiasocialis.lt/jbse/?q=node/1403

Pospiech, G., & Fischer, H. E. (2022). Physical–mathematical modelling and its role in learning physics. In Physics education (pp. 201-229). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-87391-2_8

Prastawa, S., & Radiyanto, A. (2024). Efektivitas model pembelajaran problem based learning berbasis era pasca pandemi covid 19 untuk meningkatkan berfikir kritis peserta didik. *Brilliant Journal of Education*, *1*(1), 5-14. https://doi.org/10.62952/brijoe.v1i1.16

Rachmawati, O. Q., Purwaningsih, E., & Parno. (2024). Improvement of students' problem-solving skill on physics learning: A meta-analysis. *Berkala Ilmiah Pendidikan Fisika*, *12*(2). https://doi.org/10.20527/bipf.v12i2.18462

Rahmadani, M., Kabir, A. K., Kurniawan, H., Akbar, M. D. A., & Nasir, M. (2026). Efektivitas strategi pembelajaran kolaboratif berbasis pedagogik dalam meningkatkan keterampilan sosial siswa. *Pedagogika: Jurnal Ilmu-Ilmu Kependidikan*, *6*(1), 43-51. https://doi.org/10.57251/ped.v6i1.2050

Robledo-Giraldo, S., Figueroa-Camargo, J. G., Zuluaga-Rojas, M. V., Vélez-Escobar, S. B., & Duque-Hurtado, P. L. (2023). Mapping, evolution, and application trends in co-citation analysis: A scientometric approach. *Revista de Investigación, Desarrollo e Innovación*, *13*(1), 201–214. https://doi.org/10.19053/20278306.v13.n1.2023.16070

Singh, V. K., Singh, P., Karmakar, M., Leta, J., & Mayr, P. (2021). The journal coverage of web of science, Scopus and dimensions: A comparative analysis. *Scientometrics*, *126*(6), 5113–5142. https://doi.org/10.1007/s11192-021-03948-5

Suciati, S., Silvita, S., Prasetyo, O., Fauziah, M. D., Santika, K. D., Norawi, A. M., & Rahman, H. T. (2023). Problem-based learning models: their effectiveness in improving creative thinking skills of students with different academic skills in science learning. *Jurnal Pendidikan IPA Indonesia*, *12*(4), 672-683. https://doi.org/10.15294/jpii.v12i4.44752

Sujanem, R., & Suwindra, I. N. P. (2023). Problem-based interactive physics e-module in physics learning through blended PBL to enhance students' critical thinking skills. *Jurnal Pendidikan IPA Indonesia*, *12*(1), 135–145. https://doi.org/10.15294/jpii.v12i1.39971

Suprapto, N., Rizki, I. A., & Cheng, T.-H. (2024). Profile of students' physics critical thinking skills and prospect analysis of project-oriented problem-based learning model. *Journal of Educational and Social Research*, *14*(3), 134. https://doi.org/10.36941/jesr-2024-0062

Trisnayanti, Y., Sunarno, W., Masykuri, M., Sukarmin, S., & Jamain, Z. (2023). Determining students' higher thinking skills profile using creative problem-Solving model indicators integrated with

predict observe explain. *Jurnal Pendidikan IPA Indonesia*, *12*(3), 387–400. https://doi.org/10.15294/jpii.v12i3.44650

Wijaya, T. P., Mundilarto, & Wilujeng, I. (2024). Development of Problem Based Learning collaborative (PBL-C) Physics e-Worksheet to improve student Problem solving and collaboration skills. *Jurnal Penelitian Pendidikan IPA*, *10*(1), 47–54. https://doi.org/10.29303/jppipa.v10i1.5284

Xu, E., Wang, W., & Wang, Q. (2023). The effectiveness of collaborative problem solving in promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanities and Social Sciences Communications*, *10*, Article 16. https://doi.org/10.1057/s41599-023-01508-1