Journal of Natural Science and Integration
P-ISSN: 2620-4967|E-ISSN: 2620-5092
Vol. 9, No. 1, April 2026, pp 114-132

Available online at:
http://ejournal.uin-suska.ac.id/index.php/JNSI
DOI: 10.24014/jnsi.v9i1.39168

# Emerging Trends of Technology-Integrated Problem-Based Learning in Physics Problem Solving: A Bibliometric Analysis (2015–2025)

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**ABSTRACT**
*This study aims to map and analyze research trends in technology-integrated problem-based learning (PBL) for physics problem-solving from 2015 to 2025. A quantitative bibliometric design was employed using the Scopus database as the primary data source. An initial search identified 49,401 documents, which were filtered using the PRISMA framework based on relevance, publication year, and screening criteria, yielding 154 publications for the final analysis. Data were analyzed using VOSviewer to examine publication trends, document types, subject areas, country contributions, and keyword co-occurrence networks. Additionally, the ten most highly cited articles were narratively reviewed to identify dominant research directions. The findings reveal a significant increase in publications, particularly in the last two years, indicating rapid growth in this field. Network and overlay visualizations show that problem-solving occupies a central position and is strongly connected to machine learning, deep learning, and intelligent learning systems. At the same time, PBL remains an emerging and less dominant theme. These findings indicate that although research on educational technologies in physics learning is rapidly expanding, the integration of Problem-Based Learning remains limited, highlighting an underexplored intersection between technological advancement and pedagogical implementation in physics education. The study concludes that this gap represents a key direction for future research in strengthening technology-integrated Problem-Based Learning to enhance students' physics problem-solving skills.*

**Keywords**: *bibliometric analysis, physics, problem solving, problem-based learning, technology.*

## INTRODUCTION

Problem-solving skills are an essential competency in physics learning because they are related to conceptual mastery, scientific reasoning, and students' readiness to face the challenges of 21st-century learning (Parno et al., 2020). Various studies have shown that physics learning continues to face difficulties in developing optimal problem-solving skills, especially when the learning process remains dominated by conventional approaches (Parno et al., 2020). A diagnostic study involving 163 high school students in Indonesia found that students' problem-solving skills were in the moderate range, while their conceptual understanding and numerical abilities were in the low range, indicating that students still experience difficulties comprehensively solving physics problems (Asriadi et al., 2025). These findings align with international research that reported an average score of students' physics problem-solving skills of only 42.2 on a scale of 100 (SD = 19.6), indicating low achievement and high variation in abilities among students (Musengimana et al., 2025). This situation underscores the importance of systematically reviewing research on innovations in physics learning.

One relevant physics learning innovation to address these challenges is Problem-Based Learning. Problem-Based Learning (PBL) has been widely recognized as a learning approach that encourages active student engagement by presenting contextual problems relevant to real life (Prahani et al., 2022). In the context of physics education, PBL has been shown to support the development of problem-solving skills through investigative activities and problem-based discussions (Prahani et al., 2022). As the adoption of digital technology in global education accelerates, physics education must adapt to a technology-based learning ecosystem that is flexible, collaborative, and oriented toward the development of 21st-century skills (OECD, 2021; UNESCO, 2021). The integration of technology into science learning, such as physics, is seen as a strategic necessity to improve learning quality, student engagement, and the development of higher-order thinking skills, including problem-solving abilities (Bond et al., 2020; OECD, 2021). The digital transformation in education has been further accelerated by the post-pandemic learning paradigm shift, which has pushed technology beyond a supporting tool to an integral part of learning design (Hodges et al., 2020; Trust & Whalen, 2020). In line with the development of educational technology, integrating technology into problem-based learning (PBL) provides opportunities to enrich the physics learning experience through digital and interactive means (Sunarti et al., 2024). Technologies such as digital textbooks, 3D animations, and online learning platforms are increasingly used to support the PBL process (Sunarti et al., 2024). This situation highlights the importance of systematic reviews for understanding and mapping research trends in technology integration in Problem-Based Learning (PBL) in the context of physics problem-solving.

The potential of technology-integrated Problem-Based Learning to improve problem-solving can also be understood from theoretical perspectives. From the perspective of Cognitive Load Theory, learning becomes more effective when instructional supports help reduce unnecessary cognitive load and assist students in building knowledge structures for problem solving (Paas & Merriënboer, 2020; Skulmowski & Xu, 2022). In technology-integrated learning, digital tools such as simulations, visualizations, and scaffolds can serve as these supports. In addition, social constructivist theory emphasizes that learning develops through social interaction, scaffolding, and active knowledge construction in meaningful problem contexts (Vygotsky, 1978). Viewed from these perspectives, integrating technology into Problem-Based Learning may support students both cognitively and collaboratively, thereby strengthening problem-solving processes in physics.

Bibliometric analysis is a quantitative approach used to map research developments based on scientific publications in a specific field of study (Donthu et al., 2021). This approach allows researchers to objectively and measurably identify publication trends, country contributions, Author collaborations, and research theme developments (Aria & Cuccurullo, 2017). In physics education, bibliometric analysis has been used to examine research trends in project-based learning, gamification, and other innovative learning approaches (Haryandi et al., 2024; Farkhan et al., 2025). However, bibliometric studies specifically mapping technology integration in PBL for physics problem-solving are still relatively limited (Dwikoranto et al., 2024). To ensure rigor and transparency in the literature selection process, the PRISMA framework was used as a systematic guide, encompassing the stages of Identification, Screening, Eligibility, and Inclusion (Page et al., 2021a). The application of PRISMA ensures that the analyzed documents are relevant and high-quality, thereby increasing the reliability of the research trend-mapping results (Page et al., 2021b). Therefore, the combination of bibliometric analysis and PRISMA was the appropriate approach in this study.

Research over the past decade has shown an increase in publications on the application of PBL in physics learning, at both secondary and higher education levels (Dwikoranto et al., 2024). Furthermore, the integration of educational technology has emerged as a growing research focus, particularly through the use of digital media and online learning (Sunarti et al., 2024). Recent bibliometric studies indicate that physics education research is increasingly moving toward technology-based approaches and innovative learning (Haryandi et al., 2024). However, most studies still focus on learning effectiveness and have not examined the development of research themes longitudinally (Farkhan et al., 2025). This situation has limited understanding of research development patterns and the emergence of new themes in the integration of PBL and technology in physics problem-solving. Bibliometric analysis spanning 2015–2025 allows for a more comprehensive and sustainable identification of research dynamics (Donthu et al., 2021). Therefore, a mapping of research trends is needed to illustrate the direction and focus of emerging research in this field.

Understanding emerging research trends has important implications for the development of technology-based physics research and learning practices (Dwikoranto et al., 2024). The results of this bibliometric mapping can serve as a reference for researchers to determine relevant research topics and identify open research gaps (Aria & Cuccurullo, 2017). Furthermore, information on country contributions, Author collaborations, and dominant themes can support strategic decision-making in the development of physics education curricula and policies (Haryandi et al., 2024). Based on this background, this study aims to map and analyze research trends on technology-integrated problem-based learning in physics problem-solving during 2015–2025. This study uses a bibliometric approach with the PRISMA framework to ensure a systematic and transparent literature selection process (Page et al., 2021a).

Thus, this study is expected to contribute by providing a comprehensive bibliometric mapping of research trends in technology-integrated Problem-Based Learning in physics problem-solving over the period 2015–2025, identifying the temporal evolution of research themes, and highlighting existing thematic gaps that may inform future research directions. Given the limited bibliometric studies that specifically examine the integration of technology within Problem-Based Learning in physics education, this study addresses this gap by focusing on such integration using a systematic bibliometric approach.

## METHODOLOGY

### Research Design

This study uses a quantitative approach and bibliometric methods to examine research on technology integration in Problem-Based Learning (PBL) to foster scientific problem-solving skills. Bibliometric analysis is widely used in science education research to map research trends, Analyze Author collaborations, and objectively assess studies based on scientific publication data (Donthu et al., 2021; Aria & Cuccurullo, 2017; Nugraha et al., 2022). Bibliometric analysis enables objective mapping of publication trends, collaboration patterns, and the intellectual structure of a field of study using scientific publication data. To ensure transparency and consistency in the literature selection process, this study integrates the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. Furthermore, this study conducted an in-depth review of the ten articles with the highest number of citations in Scopus to gain a substantive understanding of the most influential research contributions.

*Bibliometric Analysis Flow*

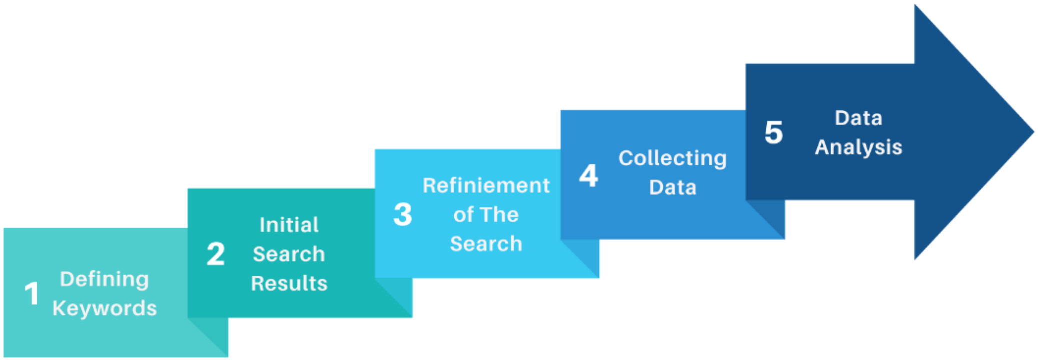



**Figure 1. Research Bibliometric Analysis Process Flow (Lintangesukmanjaya Et Al., 2025; Dawana Et Al., 2022)**

Figure 1 presents the bibliometric analysis flow used in this study. The process begins with keyword determination, initial search, search result refinement, data collection, and data analysis. The selected data were then analyzed using VOSviewer software to visualize annual publication trends, document types, subject areas, country contributions, and keyword co-occurrence networks. The data entered into VOSviewer was the result of a screening phase limited to publication years 2015–2025. The analysis meets the topic relevance criteria, indicating that it is a current and valid research map (Eck & Waltman, 2020; Nugroho & Permanasari, 2021). Network visualization was used to identify dominant and emerging research themes in the study of technology integration in PBL.

*Literature Selection Process Using PRISMA*

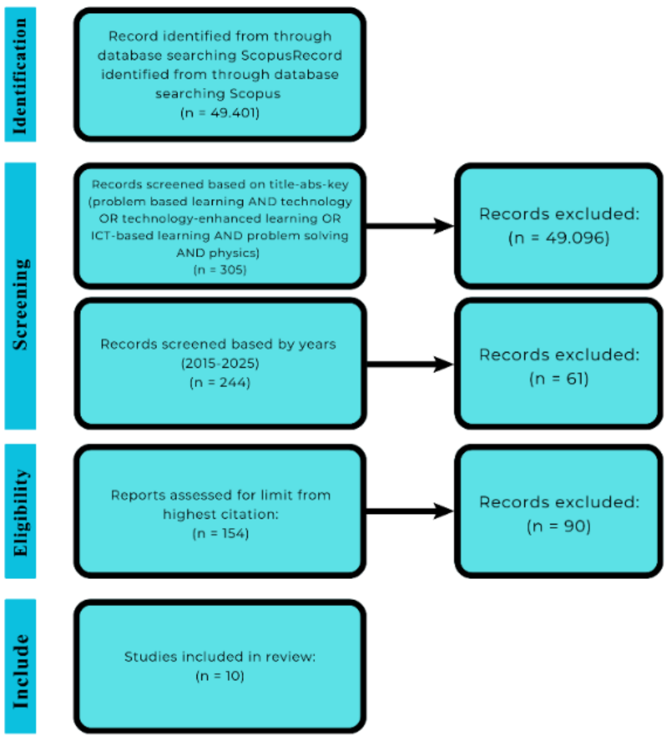



**Figure 2. PRISMA Flowchart of The Document Selection Process**

Figure 2 shows the literature selection process using the PRISMA flowchart. The use of PRISMA in bibliometric studies is recommended to increase transparency, replication, and accountability of the literature selection process, including in science education and learning (Page et al., 2021; Suryawati et al., 2023). In the identification stage, 49401 documents were retrieved from the Scopus database via searches of the title, abstract, and keywords, using combinations of terms related to Problem-Based Learning, technology, problem-solving, and physics. Duplicate records were removed prior to screening. In the screening stage, records were automatically filtered by publication year (2015–2025) and keyword relevance, yielding 244 documents. Relevance was defined as studies explicitly related to technology-integrated Problem-Based Learning in physics and associated with problem-solving. Subsequently, the authors conducted a manual eligibility assessment of titles and abstracts using predefined inclusion and exclusion criteria, resulting in 154 eligible documents. These 154 documents constituted the bibliometric dataset analyzed using VOSviewer. From this dataset, the 10 most highly cited articles were selected for in-depth analysis, as they represent influential reference studies in the development of this research field.

**Table 1. Screening and Selection Criteria**

| Stage | Procedure | Criteria Applied |
|---|---|---|
| Identification | Initial retrieval from Scopus database | Records identified through keyword search (n = 49401) |
| Screening | Automated filtering | Publication year (2015–2025), keyword relevance |
| Eligibility | Manual title and abstract review | Studies focused on technology-integrated PBL in physics problem solving (154 documents retained for bibliometric analysis) |
| Include | Selection for in-depth analysis | Top 10 most-cited articles selected based on citation counts as influential reference studies |

## Review of Highest-Cited Articles

The ten articles with the highest citation counts that passed the inclusion stage were narratively reviewed using a citation classics approach to identify major findings and complement the bibliometric results. A top-10 subset was purposively selected to enable in-depth analysis of influential publications while maintaining a manageable scope for qualitative synthesis. Highly cited publications are commonly treated as representative studies reflecting dominant research directions and intellectual influence in a field (Memon et al., 2023).

# RESULT AND DISCUSSION

## Publication Trends Over Time (2015–2025)

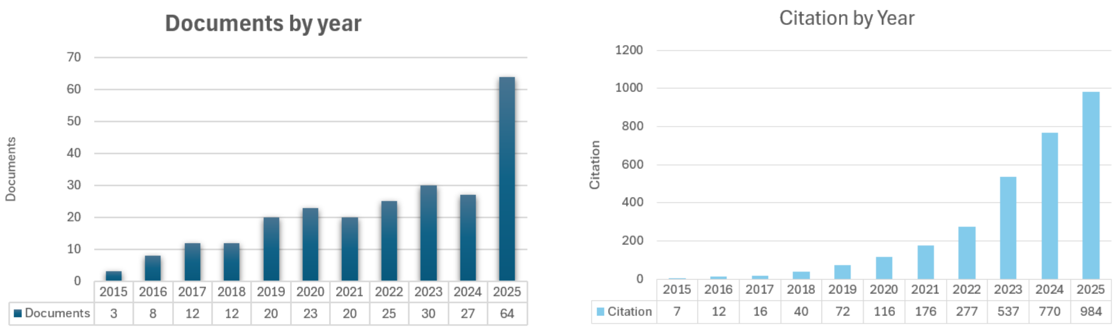



**Figure 3. Annual Publication Trends from 2021 to 2025**

The Documents by Year chart in Figure 3 shows a clear increase in publications on technology-integrated problem-based learning in physics problem-solving during the 2015–2025 period. In 2015, there were 3 publications. This number increased to 8 in 2016, then increased again to 12 in 2017. In 2018, the number of publications remained relatively stable at 12, then increased to 20 in 2019. The increase continued in 2020, with 23 documents, but decreased slightly in 2021 to 20 documents. After that, the number of publications increased again in 2022 with 25 documents and increased significantly in 2023 to 30 documents. In 2024, the number of publications decreased slightly to 27 documents, before finally experiencing a sharp spike in 2025 to 64 documents, the highest during the observation period. Overall, the graph shows a significant upward trend in publications, particularly in the last two years.

The increasing number of publications indicates that the topic of technology-integrated problem-based learning in physics problem-solving is gaining increasing attention from the academic community. The gradual increase during the 2015–2019 period indicates the initial phase of research development, in which the topic is beginning to be recognized and explored on a limited basis. Small fluctuations in 2021 and 2024 indicate that research development is not always linear, but still shows an overall upward trend. The very significant surge in 2025 indicates that research in this area is entering a phase of rapid growth. It aligns with the increasing global focus on technology-based learning and the development of problem-solving skills as key competencies in 21st-century education (OECD, 2021; UNESCO, 2023).

This trend indicates that technology integration in PBL for physics problem-solving is no longer optional but is increasingly viewed as a strategic approach in physics education. The integration of technologies such as digital simulation, Augmented Reality, and e-scaffolding in Problem-Based Learning has become an important focus in physics education research to strengthen conceptual understanding and higher-order thinking skills (Halim, 2025). Thus, these results reinforce the finding that this research area is still wide open for further development and has great potential for future research, particularly in the context of physics problem-solving.

## Document Types

Analysis of document types shows that research on technology-integrated problem-based learning in physics problem-solving is primarily published as journal articles and conference papers. Of the 244 documents identified in the dataset, journal articles were the most dominant publication type, accounting for 104 documents (42.6%). Conference papers followed with 98 documents, or 40.2 percent. Other document types appeared in smaller proportions, including review articles (18 documents, or 7.4 percent), conference reviews (14 documents, or 5.7 percent), book chapters (8 documents, or 3.3 percent), and books (2 documents, or 0.8 percent). This data is illustrated in Figure 4 below.

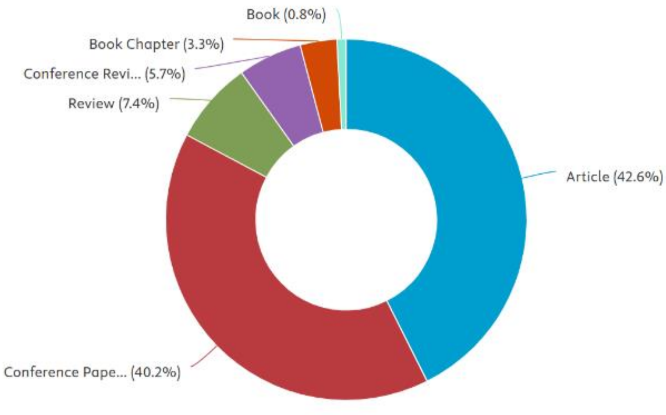



**Figure 4. Distribution of Document Types**

The dominance of journal articles indicates that research on technology-integrated problem-based learning in physics problem-solving has reached a level of academic maturity. It is marked by an increase in systematic reviews and publications in reputable journals that implement rigorous peer-review processes (Donthu et al., 2021; Aria & Cuccurullo, 2017). Journal publications generally demand robust research designs and methodological clarity, reflecting a growing focus on evidence-based learning practices. The high proportion of conference papers also demonstrates active academic engagement in presenting innovative learning models, digital tools, and instructional frameworks relevant to physics education.

The presence of review articles demonstrates increasing efforts to synthesize existing research findings and organize accumulated knowledge in this field. This development reflects the growing number of empirical studies that can be analyzed integratively. The limited number of book chapters and books suggests that research in this field places greater emphasis on empirical and applied contributions. Bibliometric research on Technology-Assisted Problem-Based Learning shows an annual upward trend in the number of journal articles, confirming that research in this field is oriented toward empirical contributions published in scientific journals (Nurhayati et al., 2024). Overall, the distribution of document types suggests that this area of research is productive and continues to grow with a focus on technological innovation and problem-based learning in physics education.

**Subject Areas**

Analysis of scientific fields shows that research on technology-integrated problem-based learning in physics problem-solving spans various disciplines. Physics and Astronomy were the largest contributors, with 84 documents, or 19.0 percent of the total publications. Computer Science followed with 79 documents, or 17.9 percent, followed by Social Sciences with 77 documents, or 17.5 percent. The distribution of these scientific fields is shown in Figure 5.

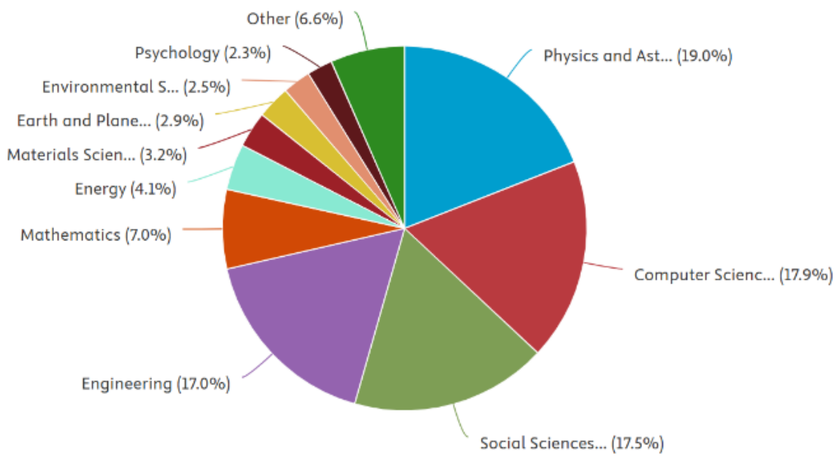



**Figure 5. Distribution of Subject Areas**

The dominance of Physics and Astronomy confirms that the primary focus of this research remains on physics education. The high contribution from Computer Science reflects the important role of digital technology, learning systems, and computational approaches in supporting problem-based learning. The involvement of Engineering demonstrates the relevance of developing learning designs and implementing technology in the context of physics problem-solving. It aligns with bibliometric findings showing an increase in publications on problem-solving-oriented physics learning, with Problem-Based Learning (PBL) among the approaches most studied in the past decade (Lintangesukmanjaya et al., 2025).

Another significant contribution comes from the Social Sciences, which demonstrates attention to pedagogical aspects, learning interactions, and students' cognitive processes in the application of technology-integrated problem-based learning. These findings reinforce the view that technology integration in learning requires support from pedagogical and social studies to ensure the effectiveness of the learning process, as demonstrated by a bibliometric analysis highlighting the significant role of the social sciences in research on educational technology integration (Lintangesukmanjaya et al., 2025). Mathematics plays a significant role in supporting the development of quantitative reasoning and mathematical modeling in physics learning. The involvement of applied fields such as Energy, Materials Science, and Environmental Science indicates that this approach is often used in the context of contextual and applicable physics problems. Overall, the distribution of scientific fields demonstrates the strong interdisciplinary character and relevance of this approach to the needs of contemporary physics education.

**Country Contributions**

Analysis of countries and regions shows that research on technology-integrated problem-based learning in physics problem-solving involves contributions from a wide range of countries. Indonesia may indicate the leading contributor with the highest number of publications in the dataset. The United States and China followed, indicating strong research activity in developing technology-integrated physics learning. Malaysia and the United Kingdom also made significant contributions, reflecting the presence of active research communities in the region. Additional contributions came from Ukraine, Kazakhstan, the Netherlands, Australia, and India. The distribution of publications by country or region is shown in Figure 6.

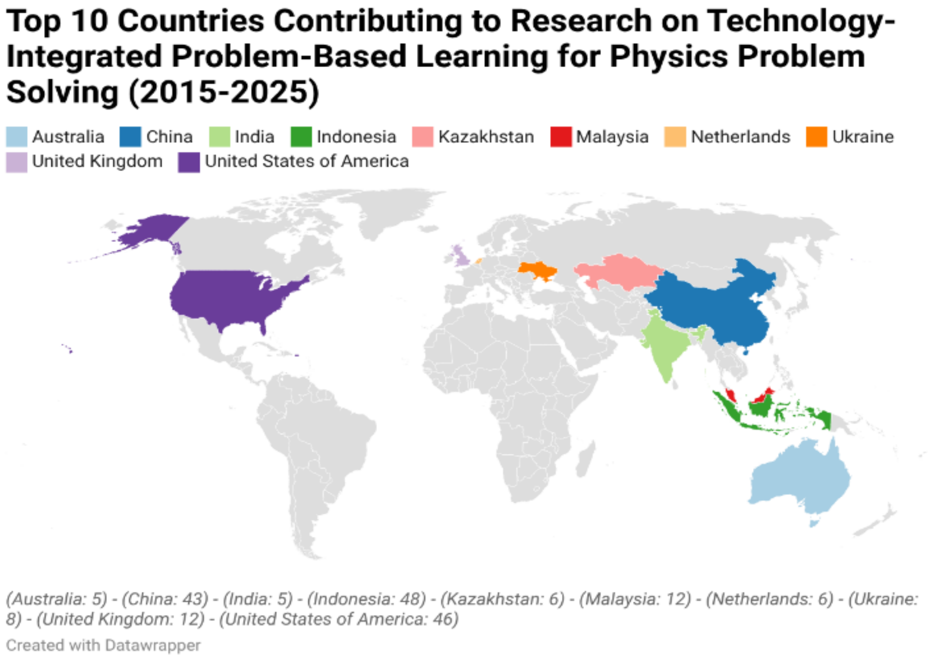



**Figure 6. Top 10 Contributing Countries**

The high number of publications from Indonesia reflects a strong focus on innovative learning strategies and technology integration in physics education research. This pattern aligns with the implementation of a learner-centered learning approach and the emphasis on developing problem-solving skills in national education policies (MoECRT, 2022). In addition, the increasing number of research dissemination activities, including national and international conferences, may also contribute to the high publication output. However, such productivity should be interpreted cautiously, as a higher number of publications does not necessarily reflect greater citation impact or international research influence (Tahamtan & Bornmann, 2019). Therefore, research productivity should be measured by research quality and global visibility, rather than just the number of publications. Contributions from the United States and China demonstrate a continued commitment to educational technology research and the development of digital learning environments in science education.

The presence of publications from Asia, Europe, and other regions demonstrates that technology-integrated problem-based learning in physics problem-solving has global relevance. The geographic distribution of these publications reflects the breadth of international academic attention to the topic under study, which, in bibliometric studies, is used as an indicator of a research field's global relevance and attractiveness (Donthu et al., 2021). Overall, the country/region analysis indicates that an internationally dispersed academic community supports this research field.

**Network Visualization of Research Themes**

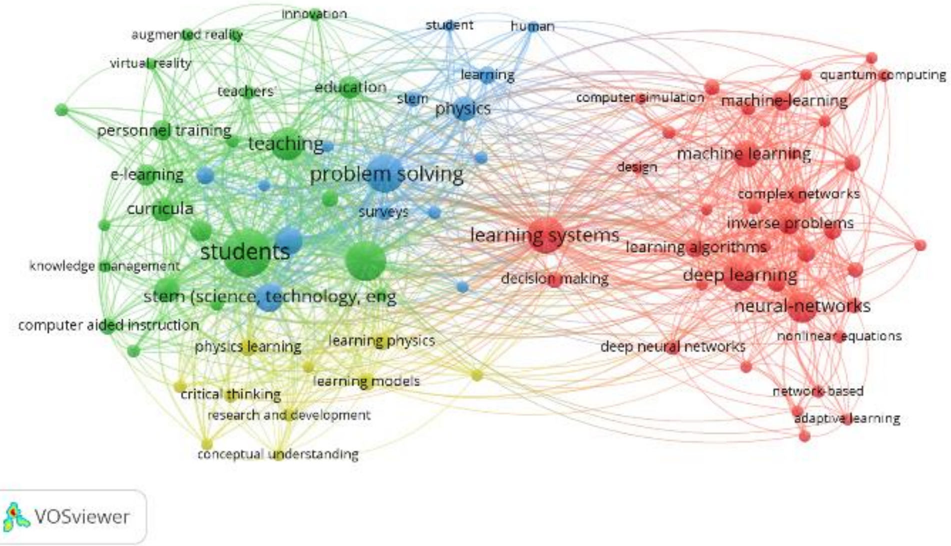



**Figure 7. Keyword Co-Occurrence Network**

The keyword co-occurrence network visualization shows the thematic structure of research on technology-integrated problem-based learning in physics problem solving. This map forms several color-coded keyword clusters, where the frequency of occurrence (occurrences) is represented by node size, while the relationships between nodes indicate the strength of the association (co-occurrence) between keywords in the analyzed publications (Eck & Waltman, 2010; Donthu et al., 2021). The green cluster comprises 24 items and covers the themes of learning practices, learners, and educational contexts, with dominant keywords including students, teaching, education, STEM, e-learning, curriculum, and physics learning. This cluster demonstrates a research trend that places learners at the center of the learning process and utilizes digital technology to support active learning. This pattern aligns with 21st-century learning principles that emphasize student engagement through technology integration in science and physics learning (Halim, 2025).

The blue cluster focuses on the core concept of physics problem-solving and consists of 14 items, with key keywords such as problem-solving, physics, learning, problem-based learning, and student. This cluster highlights studies on cognitive processes, learning outcomes, and the development of conceptual understanding in physics education. The relatively central position of this cluster demonstrates its role as a bridge between pedagogical approaches and the application of technology. This finding is consistent with studies reporting that applying PBL in physics learning significantly improves students' problem-solving abilities and conceptual understanding (Sari, 2023).

The red cluster is the largest, with 89 items. It represents a technology- and computational-oriented research orientation, characterized by keywords such as machine learning, deep learning, neural networks, learning systems, and computer simulation. This cluster demonstrates the increasing use of artificial intelligence and computational-based learning systems to support physics learning. The strong relationship between the red and blue clusters indicates that intelligent technology is increasingly being utilized to support physics problem-solving and the understanding of abstract concepts (Feziyasti, 2025).

The yellow cluster includes 11 items and relates to higher-order learning outcomes and the development of learning models, with keywords such as critical thinking, conceptual understanding, learning models, and research and development. This cluster reflects research's focus on developing higher-order thinking skills through technology-integrated problem-based learning (Halim, 2025). The 10 most frequently used keywords in technology-integrated problem-based learning for physics problem solving between 2015 and 2025 are presented in Table 2.

**Table 2. Top 10 Keywords in Technology-Integrated Problem-Based Learning in Physics Problem Solving (2015–2025)**

| Keywords | Occurrences | Total Link Strength |
|---|---|---|
| Students | 68 | 358 |
| Engineering education | 46 | 262 |
| Problem Solving | 42 | 216 |
| Learning systems | 39 | 215 |
| Teaching | 32 | 193 |
| Neural-network | 27 | 143 |
| Deep learning | 29 | 141 |
| Stem (science, technology, engineering and mathematics | 24 | 133 |
| Machine Learning | 22 | 81 |
| Physics | 18 | 66 |

Table 1 presents the ten keywords with the highest frequency of occurrence and total link strength. The dominance of the keywords "students" and "problem-solving" confirms that student engagement and problem-solving skills are the primary focus of research. Meanwhile, the high linkage scores for technology-based keywords such as "learning systems," "machine learning," and "deep learning" indicate that pedagogical and technological approaches are often combined in these studies. This finding aligns with the literature, which indicates that PBL combined with digital media or electronic modules is effective in strengthening critical thinking and problem-solving skills in physics learning (Novianti, 2025). Overall, the network visualization and keyword distribution results indicate that research on technology-integrated PBL in physics problem-solving is developing within three main themes: developing student thinking skills, utilizing digital technology, and linking physics learning with STEM approaches. This pattern reflects the consolidation of a research field that is adapting to the demands of modern education and the need to improve the effectiveness of physics learning (OECD, 2021; Sung et al., 2022; UNESCO, 2023).

**Overlay Visualization Of Research Topics**

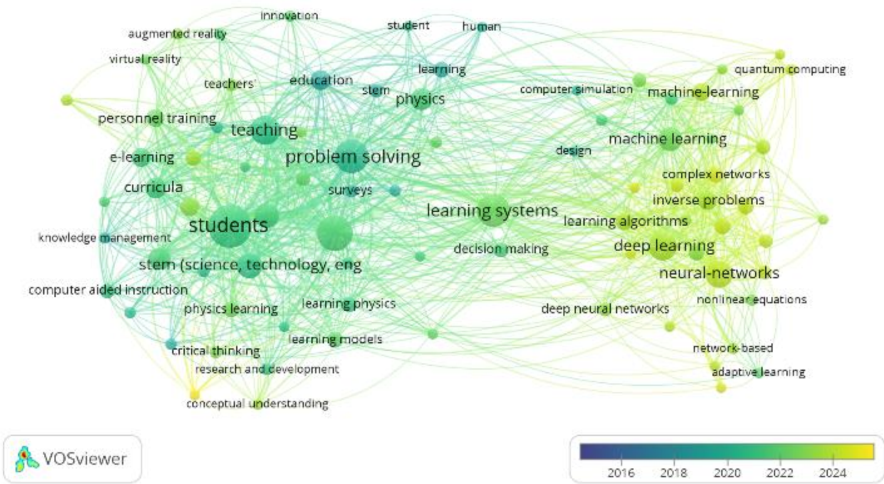
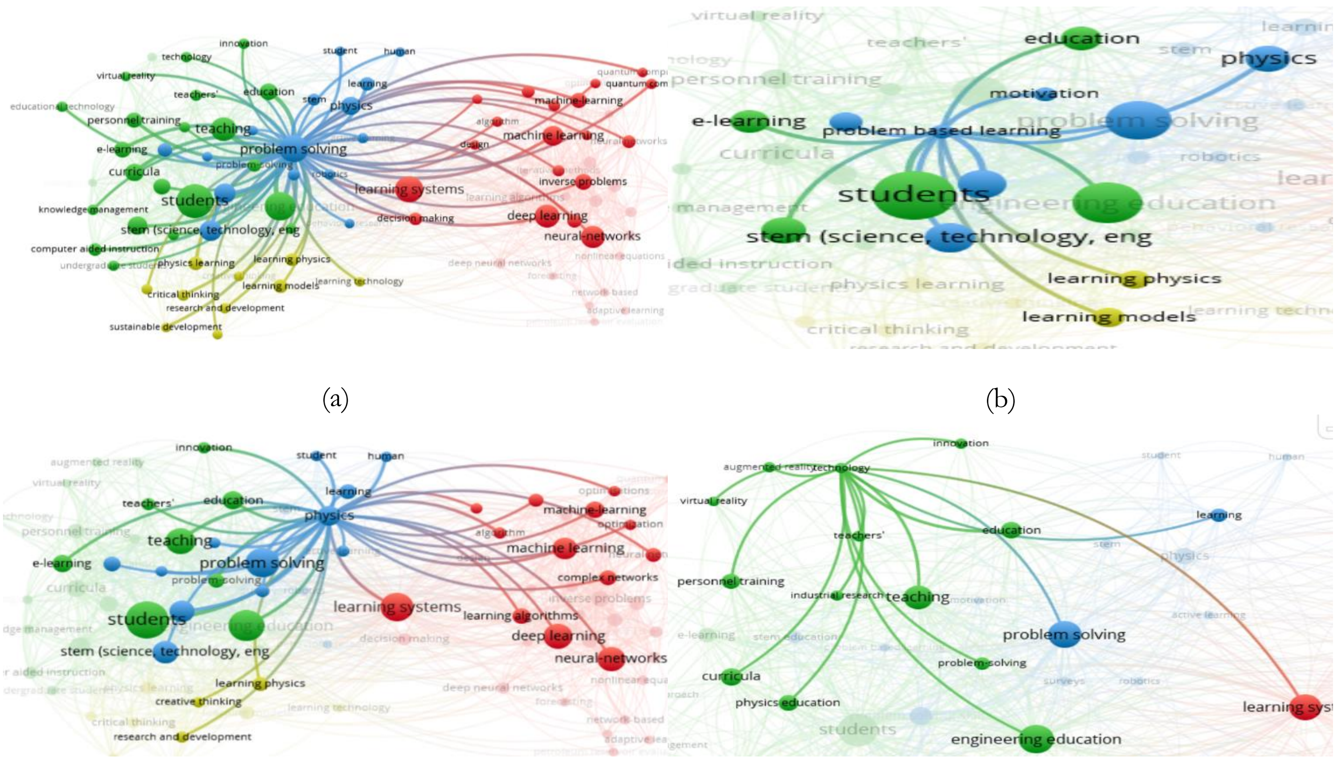



**Figure 8. Overlay Visualization of Keyword Evolution**

This overlay visualization shows the temporal development of research themes in technology-integrated problem-based learning (PBL) in physics problem-solving. The color gradient represents the average year of publication of keywords, allowing identification of research themes based on the timing of their emergence and shifts in focus (Eck & Waltman, 2010; Donthu et al., 2021). Keywords such as "teaching," "students," "education," "physics," "STEM," and "problem-solving" are colored darker, indicating that early research focused more on pedagogical aspects, student engagement, and problem-solving processes in physics education. These themes form the conceptual foundation for subsequent research development.

Themes in green to light green, such as e-learning, computer simulation, and learning models, indicate an intermediate development phase characterized by increasing attention to the use of digital technology and technology-based learning design in PBL. The most recent themes are represented by yellow keywords, including machine learning, deep learning, and learning algorithms, indicating a shift in research toward the development of intelligent learning systems and advanced computational approaches to support more complex physics problem-solving. Overall, the overlay visualization shows that the research direction is evolving from a pedagogical focus toward the integration of increasingly sophisticated digital technologies in problem-based learning within the context of physics problem-solving.

**Relationship Between Keywords**




(a) (b)

(c) (d)

**Figure 9. Keyword Relationships Focusing on (a) Problem Solving, (b) Problem-Based Learning, (c) Physics, and (d) Technology**

Figure 9(a) shows that problem-solving occupies a central position and is closely linked to pedagogical keywords such as students, teaching, education, and physics. This pattern indicates that problem-solving serves as a primary learning objective, linking teaching strategies, student engagement, and physics content. The link to STEM indicates that problem-solving is often studied in interdisciplinary learning contexts and is oriented toward the application of concepts. This finding aligns with recent research confirming that physics learning that focuses on problem-solving encourages active student engagement in reasoning, analysis, and the contextual application of physics concepts (Putri et al., 2024).

Figure 9(b) shows that problem-based learning has strong links to students, motivation, education, and STEM. This network structure indicates that PBL is positioned as a student-oriented pedagogical approach and is associated with increased learning motivation. The link to engineering education indicates that PBL is widely applied in applied and interdisciplinary learning contexts. These results are consistent with empirical findings reporting that PBL in physics learning effectively increases student motivation and engagement, especially when learning is designed around real-world problems and STEM contexts (Novianti et al., 2025).

Figure 9(c) shows that physics is closely linked to problem-solving, learning, and students. This pattern emphasizes the role of physics as the primary scientific context in the application of problem-based learning. The link between physics and learning systems indicates that learning technology is utilized to support the physics learning process, particularly in helping students understand concepts and solve problems. This finding aligns with recent physics education studies that emphasize that technology integration is effective when used to strengthen conceptual understanding and problem-solving skills, rather than as a stand-alone learning objective (Hidayati et al., 2024).

Figure 9(d) shows that technology acts as the main node connecting pedagogical aspects and learning objectives. This node branches directly to problem-solving and learning systems and is connected to educational keywords such as teaching and education. This structure emphasizes that technology is not positioned as a learning objective, but rather as a tool that facilitates the problem-solving process and the implementation of learning systems. The relationship between technology and problem-solving demonstrates the orientation toward utilizing technology to support learning outcomes. In contrast, the relationship with learning systems reflects the application of technology in the form of digital learning systems. This pattern demonstrates the role of technology as a link between pedagogical approaches and learning outcomes in physics, aligning with recent research findings that emphasize the importance of integrating pedagogically grounded technology into science learning (Putri et al., 2024; Novianti et al., 2025). Overall, the visualization demonstrates an integrated research structure, with problem-solving as the conceptual core, problem-based learning as the pedagogical approach, physics as the scientific context, and technology as a support for learning implementation.

## Review of the Ten Most Highly Cited Articles

The review was conducted to identify the most influential publications on technology-integrated problem-based learning in physics problem-solving. The ten articles with the highest number of citations were selected based on Scopus data because they demonstrated significant academic impact. These articles represent the main themes and dominant methodological approaches in research related to technology integration, problem-based learning, and the development of higher-order thinking skills.

**Table 3. Overview of the Ten Most Highly Cited Articles**

| Author (Year) | Citation; SJR | Finding |
|---|---|---|
| **Farrag et al. (2024)** | 47; 0,99 (Q1) | This research shows that integrating physics constraints into machine learning models improves predictive accuracy and model stability. This approach supports complex problem solving by combining data-driven learning and physics principles. |
| **Tajjour dan Chandel (2023)** | 104; 1.61 (Q1) | The study results show that machine learning methods improve the efficiency of energy system modeling and support decision-making processes. Intelligent algorithms play a role in solving complex sustainability problems. |
| **Diao et al. (2023)** | 81; 2.41 (Q1) | This study shows that a hybrid model based on learning and computation improves the accuracy of solutions to physics problems involving multiple materials. |
| **Tschisgale et al. (2023)** | 54; 1.49 (Q1) | The findings show that the use of artificial intelligence supports the learning process by increasing student engagement and problem-solving abilities in the context of physics. |
| **Muther et al. (2022)** | 44; 3,01 (Q1) | This study shows that combining the laws of physics with machine learning improves model explainability and reliability, thereby supporting scientific and engineering problem solving. |
| **Zuo et al. (2021)** | 678; 5.02 (Q1) | The results of the study show that deep learning techniques improve measurement accuracy and problem-solving efficiency in optical systems. |
| **Gao et al. (2021)** | 46; 2.48 (Q1) | This study shows that iterative learning-based optimization improves system performance and supports decision making on complex engineering problems. |

| Author (Year) | Citation; SJR | Finding |
|---|---|---|
| **Khan et al. (2021)** | 104; 2.93 (Q1) | The results of the study show that machine learning models improve predictive capabilities and help solve complex problems in process systems. |
| **Huang et al. (2021)** | 56; 0.94 (Q1) | This research shows that short-term quantum algorithms have the potential to solve large-scale linear systems in the context of physics and computation. |
| **Mousavinasab et al. (2020)** | 449; 1.98 (Q1) | This study shows that the intelligent tutoring system supports personalized learning through adaptive feedback and contributes to the development of learners' problem-solving abilities. |

Based on the review results in Table 2, the majority of research focuses on the use of intelligent computational technologies, such as machine learning, deep learning, and hybrid models based on physics principles, to improve analytical accuracy and efficiency in solving complex problems (Zuo et al., 2021; Muther et al., 2022; Diao et al., 2023). This approach demonstrates the critical role of technology in supporting problem-solving processes in physics and engineering contexts. Several studies emphasize integrating physics principles into machine learning algorithms to improve model stability and explainability, thereby strengthening science-based problem-solving (Farrag et al., 2024; Muther et al., 2022). These findings indicate that problem-solving is positioned as the primary goal, while technology serves as a supporting tool for scientific analysis and reasoning.

In the educational realm, research also demonstrates the potential of intelligent technologies to increase student engagement and support adaptive learning, particularly through intelligent tutoring systems and artificial intelligence-based approaches (Tschisgale et al., 2023; Mousavinasab et al., 2020). However, most of these studies still place technology as the primary focus, while pedagogical approaches, particularly problem-based learning, have not been explicitly studied as a primary research object. This situation indicates a significant research gap: the integration of problem-based learning with learning technology in the context of physics. The characteristics of PBL, which emphasize authentic problems and the development of problem-solving strategies, align with the potential of digital technologies, such as simulations and adaptive feedback systems, to enhance problem-based learning.

Overall, the articles with the highest citations demonstrate a research trend toward utilizing smart technology to support physics problem-solving. Although problem-solving is the primary focus, the integration of PBL as a pedagogical framework is still developing. It offers opportunities for further research into the design and technology of problem-based physics learning..

## Literature Findings

A review of the ten most highly cited articles indicates that machine learning and deep learning grounded in physics principles are the dominant approaches for supporting complex problem-solving. Integrating physical laws into computational models has been shown to improve the accuracy, stability, and reliability of solutions across various physics and engineering contexts (Farrag et al., 2024; Muther et al., 2022; Zuo et al., 2021).

In the context of physics learning, these findings are relevant to the characteristics of problem-based learning, which focuses on solving authentic problems. Machine learning and deep learning-based technologies have the potential to be used as analysis and simulation tools in PBL to strengthen students' reasoning and problem-solving processes, as supported by findings on the role of intelligent systems in enhancing engagement and problem-solving skills (Tschisgale et al., 2023; Mousavinasab et al., 2020).

### Emerging Research Trends

Bibliometric analysis shows that research trends in technology-integrated physics learning are increasingly shifting toward the use of machine learning, deep learning, and computational modeling to support complex problem-solving. These technologies are used as tools for analysis and decision-making, not as learning objectives in themselves (Zuo et al., 2021; Farrag et al., 2024).

Furthermore, the development of digital learning environments and adaptive systems demonstrates efforts to increase student independence and structure in problem-solving processes. In this context, problem-based learning is emerging as a relevant pedagogical approach, although it has not yet become a dominant focus. Therefore, the integration of PBL and technology in physics learning remains a growing area of research (Tschisgale et al., 2023; Diao et al., 2023).

### Future Research Directions

Based on a bibliometric analysis of technology-integrated problem-based learning in physics problem-solving, further research could examine the relationship between the type of learning technology and the problem-solving skills developed. The reviewed literature indicates the dominant use of smart technology and computational systems. Therefore, further research is needed to more specifically map the role of instructional learning technologies, such as digital simulations, interactive worksheets, and adaptive feedback systems, in supporting analytical thinking processes and conceptual understanding of physics.

Furthermore, future research could focus on implementing contextually designed problem-based learning (PBL) supported by technology. The integration of digital physics investigation-based worksheets supported by online platforms and virtual simulations has the potential to strengthen the PBL phase, particularly in problem exploration, hypothesis testing, and reflection on learning outcomes. Such studies are important for broadening understanding of the effectiveness of technology-integrated PBL at the high school level, particularly in physics topics with a conceptual-abstract nature.

### Educational Implications of the Findings

For physics teachers, the growing presence of intelligent technologies such as machine learning, deep learning, and computational modeling reflects a shifting learning environment in which digital tools can meaningfully support students' physics problem-solving. However, their effectiveness depends on alignment with constructivist principles, where knowledge is constructed through interaction and scaffolding within the zone of proximal development (Vygotsky, 1978). In this regard, Problem-Based Learning provides a relevant framework for fostering meaningful and inquiry-driven physics learning through collaborative problem-solving and knowledge construction (Hmelo-Silver, 2004). In technology-enhanced environments, these principles can be further supported through digital tools that facilitate collaboration and exploration.

For curriculum developers and instructional designers, these findings underscore the importance of aligning technological innovation with coherent pedagogical design, ensuring that digital tools serve as cognitive scaffolds rather than mere content-delivery mechanisms. Similarly, digital pedagogy designers are encouraged to structure learning environments around Problem-Based Learning cycles by integrating intelligent technologies such as simulations, machine learning applications, and computational tools to support inquiry and iterative problem-solving in physics education. Finally, for STEM education researchers, the gap between technological advancement and pedagogical integration indicates the need for further empirical studies on how technology-integrated Problem-Based Learning can be systematically implemented in authentic classrooms and how it influences students' physics problem-solving processes.

## CONCLUSION

Based on a bibliometric analysis of 154 Scopus-indexed publications from 2015 to 2025, this study reveals a growing, interdisciplinary research trend on technology-integrated problem-based learning in physics problem-solving. The analysis of documents by year, citations by year, subject areas, and country contributions indicates increasing academic interest in intelligent technologies and digital learning environments within physics education. Network and overlay visualizations show that problem-solving occupies a central position and is strongly connected to themes such as machine learning, deep learning, intelligent learning systems, and computational modeling. In contrast, problem-based learning remains an emerging and non-dominant theme. The review of the most highly cited articles further confirms that existing studies primarily emphasize technological development, with limited focus on systematic pedagogical integration of PBL in physics learning contexts. These findings highlight a research gap between technological advancement and pedagogical implementation, indicating the novelty and relevance of studies that empirically integrate problem-based learning with digital learning technologies to enhance students' physics problem-solving skills..

## ACKNOWLEDGMENTS

The Author gratefully acknowledges the Physics Education Study Program at *Surabaya State University* for providing academic support and access to scholarly resources that facilitated the preparation of this bibliometric study. Appreciation is also extended to the lecturers and academic community for their academic insights and constructive feedback, which contributed to the clarity and rigor of the analysis presented in this article.

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