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Future Research Directions of Problem-Based Learning and E-Modules In 21st-Century Physics Education: A Bibliometric Analysis

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ABSTRACT This study aims to analyze research trends and future directions related to Problem-Based Learning (PBL) and e-modules in 21st-century physics education through a bibliometric approach. An analysis was conducted of 281 scientific articles published between 2015 and 2025 and indexed in international databases, using keywords related to PBL, e-modules, and physics education. Bibliometric and VOSviewer were used to map publication trends, productive sources, and keyword networks. The results show a significant increase in publications after 2019, with PBL remaining the primary approach related to problem-solving, while e-modules serve as digital learning resources that support structured and self-directed learning. Physics education largely serves as an implementation context, indicating that the integration of PBL and e-modules specific to the physics discipline is still limited. These findings provide a strategic foundation for the development of PBL-based e-modules and serve as a guide for empirical research and curriculum innovation in 21st-century physics education.

Keywords: Bibliometric analysis, Digital learning, E-Module, Physics education, Problem-Based Learning

1. INTRODUCTION

21st-century physics learning is expected to develop 6C skills, which include critical thinking, creativity, collaboration, communication, citizenship, and character as the foundation for students' readiness to face global challenges (Fullan et al., 2021; OECD, 2022)In the context of physics, learning abstract concepts requires students to engage in higher-level reasoning and a systematic problem-solving process, as well as the material and its demands for in-depth conceptual reasoning (Kalonde et al., 2025). Furthermore, learning is expected to provide space for collaboration and scientific communication so that students can build understanding through discussion and teamwork. Creativity is also needed so that students can design various strategies for solving physics problems that are not always procedural. Citizenship and character values are expected to develop through involvement in contextual problems related to real-life issues and social responsibility. To realize this skill profile, physics learning needs to be designed based on exploratory activities that are cognitively and contextually challenging (Yew & Goh, 2016). The integration of digital learning resources such as e-modules is also expected to promote students' capacity for self-directed learning while enriching the representation of physics concepts. Thus, 21st-century physics learning is expected to combine a problem-based approach and digital technology support to develop the 6C skills in an integrated manner (Ariantini et al., 2021).

Physics learning has undergone a significant transformation in the 21st century, particularly with the integration of digital technologies, online learning environments, and student-centered pedagogies, which accelerated during and after the COVID-19 pandemic. For instance, the rapid increase in research publications on digital learning and PBL in physics education—from only 2–8 studies per year (2015–2018) to 63 publications in 2025—reflects a global shift toward more interactive and technology-supported learning environments . In real classroom contexts, the use of simulations, virtual labs, and e-modules has become increasingly common to help students visualize abstract concepts and engage in inquiry-based learning. However, despite these advancements, classroom practices in many educational settings still tend to be dominated by teacher-centered approaches that focus

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on concept delivery and routine problem-solving (Sari & Rosidah, 2023) indicating a gap between the evolving nature of physics education and its implementation in practice. This condition results in the learning process being more oriented towards end results than in-depth thinking (Smarandache et al., 2022). Consequently, opportunities for students to develop analytical reasoning and systematic problem-solving skills as part of the 6C competencies may not be fully optimized in some learning contexts. Collaborative activities and scientific communication are also sometimes limited, particularly in classrooms where instruction remains predominantly one-way. Furthermore, students' creativity in exploring various physics problem-solving strategies is still underdeveloped. Although numerous studies have explored the use of digital learning resources, including e-modules, in physics education, their integration with pedagogical models that actively promote problem exploration, such as PBL, remains uneven and often lacks instructional coherence. Previous research highlights that e-modules are frequently utilized as supplementary materials rather than being systematically embedded within inquiry-oriented learning designs (Alviz-Meza et al., 2022). As a result, the potential of digital resources to support higher-order thinking, particularly in facilitating structured problem-solving processes and conceptual understanding, has not been fully realized. Therefore, this study positions the integration of e-modules within a PBL framework as a strategic approach to create a more coherent, student-centered, and problem-oriented physics learning environment. This indicates that technology integration in learning is often complementary, rather than a core part of pedagogical design. This reality highlights the gap between expectations for 21st-century skill development and physics learning practices in the field.

The gap between the demands of developing 6C skills and physics learning practices indicates a fundamental problem in learning design, which is not yet oriented toward authentic problem-solving (OECD, 2022). Learning that still focuses on routine procedures leaves students poorly trained to connect physics concepts to complex real-world situations. This condition impacts students' ability to transfer knowledge to new contexts that require flexible reasoning. Furthermore, limited collaborative activities and problem-based discussions result in the underdevelopment of scientific communication and collaboration skills as part of the 6C competencies. This problem is further exacerbated by the suboptimal use of digital technology to support higher-order thinking processes in physics learning (Kalonde et al., 2025). While some students are able to navigate inquiry processes effectively without digital support, the availability of structured digital learning materials can provide additional scaffolding that helps many learners engage more systematically with open-ended problems. In particular, such resources can support the organization of ideas, visualization of abstract concepts, and guidance throughout the inquiry process, especially for students who require more structured learning support. These circumstances demonstrate the importance of implementing an effective instructional approach that not only presents contextual problems but also provides systematic and interactive learning support. Accordingly, the integration of the PBL model is considered essential with e-modules as a learning innovation that specifically targets strengthening problem-solving competencies aligned with the demands of contemporary education in physics education (Yew & Goh, 2016)

In response to these issues, the application of the Problem-Based Learning (PBL) approach in combination with e-modules is seen as a relevant pedagogical innovation in 21st-century physics learning. PBL encourages students to learn through exploring authentic problems, thereby stimulating critical thinking, collaboration, and scientific communication skills as part of the 6C competencies (Yew & Goh, 2016) Through group discussions and inquiry processes, students not only understand physics concepts but also develop the ability to formulate and evaluate solutions logically. Furthermore, e-modules provide a structured, interactive digital learning environment that supports independent learning. Multimedia features, simulations, and feedback in e-modules help visualize abstract physics concepts, thus strengthening students' knowledge construction process (Alviz-Meza et al., 2022).When combined, PBL provides a framework for problem-based activities, while e-modules act as scaffolding that guides students throughout the inquiry process. The integration of the two creates a more contextual, collaborative learning experience, aligned with the characteristics of 21st-century digital learning. Thus, e-module-assisted PBL has the potential to be an effective approach to developing problem-solving skills in physics education (Ernawati & Rahmawati, 2021)

The growing attention to the application of a PBL approach in combination with e-modules in physics education has driven the growth of scientific publications on this topic in recent years. This rapid growth of the literature makes it difficult for researchers to obtain a comprehensive overview of research trends, the focus of studies, and established collaboration patterns. Narrative literature reviews often fail to systematically and quantitatively map the intellectual structure of a field (Bashir & Warraich, 2023). Thus, an additional comprehensive approach is required to objectively determine dominant themes and research development directions. Bibliometric analysis allows mapping of publication trends, author collaboration networks, and keyword relationships within a field of study (Sarıkaya & Çeliker, 2024). Through this approach, researchers can uncover patterns of research development and uncover underexplored topics. To date, bibliometric studies specifically mapping the integration of PBL and e-modules in the context of physics education are still limited (Aria & Cuccurullo, 2017). Based on this, this study employs a bibliometric approach to examine publication trends, map the structure of research, and propose directions for future studies on problem-based learning and e-modules in physics education.

2. METHOD

This research was designed using a quantitative approach with bibliometric analysis to systematically map and analyze scientific publications related to PBL and e-modules in physics education. The choice of this quantitative approach is based on the ability to produce objective and measurable data processing from large amounts of publication data to identify patterns, trends, and characteristics of research in a field of study (Donthu et al., 2021).This method analyzes bibliographic data such as publication year, author, affiliation, journal source, citations, and keywords to quantitatively describe research developments. This study employed a quantitative bibliometric approach to systematically analyze publications related to PBL and digital-based learning in physics education. The data were collected from indexed international databases using predefined keywords such as “Problem-Based Learning,” “PBL,” “e-module,” and “physics education.” The selected articles were then filtered based on inclusion criteria, including relevance to the topic, publication type, and availability of full text. Furthermore, bibliographic data such as authors, publication year, source titles, citations, and keywords were extracted and processed. The analysis was conducted using VOSviewer to map author collaboration networks and identify relationships between research topics based on keyword co-occurrence. Through this procedure, the study aims to reveal research trends, dominant themes, and potential directions for future research in the integration of PBL and e-modules in physics education.

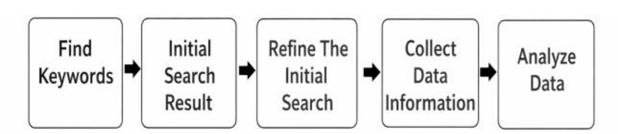


Figure 1. Research phase flow

Figure 1 presents the stages of research implementation that adopt the PRISMA-based Systematic Literature Review (SLR) framework combined with quantitative bibliometric analysis. The flow includes keyword identification, initial literature search, result screening, data collection, and systematic data analysis (Page et al., 2021). This approach is applied to ensure a systematic, transparent, and replicable literature selection process, while minimizing bias in document selection (Donthu et al., 2021). The data analyzed consisted of reputable international journal articles discussing PBL, e-modules, and physics education.

The search process was conducted using a combination of keywords such as “Problem-Based Learning,” “PBL,” “e-module,” “digital module,” and “physics education” through the application of Boolean operators. The data were collected from internationally indexed databases, specifically Scopus, covering publications within the period of 2015 to 2025. The data retrieval process was carried out in January 2026. From the initial search, a total of 281 articles were obtained, which were then subjected to screening and selection procedures based on predefined inclusion criteria. Search results were then filtered based on selection criteria, including articles that have gone through a peer review process and are relevant to the research topic of PBL or e-modules in a learning context, and related to physics education. Duplicate documents, non-research articles, and publications without full text were excluded from the analysis following the PRISMA procedure (Page et al., 2021). From the initial dataset, articles were screened based on predefined inclusion criteria, resulting in a final sample of 281 eligible articles for analysis.

The selected bibliographic data were obtained through a structured search and screening process. The search query was formulated using Boolean operators to ensure the inclusion of studies that simultaneously address Problem-Based Learning, e-modules, and physics education, for example: (“Problem-Based Learning” OR “PBL”) AND (“e-module” OR “digital module”) AND (“physics education”). This query was applied to the title, abstract, and keywords fields in the database.

The initial results were then screened in several stages. First, duplicate records were removed. Second, titles and abstracts were reviewed to ensure relevance to the integration of PBL and digital modules within the context of physics education. Third, full-text screening was conducted to confirm that the studies explicitly discussed both the implementation of PBL and the use of e-modules or digital modules in physics learning contexts.

The inclusion criteria consisted of: (1) peer-reviewed journal or conference articles, (2) publications within the specified time range, (3) studies focusing on physics education, and (4) studies that integrate both PBL and e-modules/digital modules. Articles that only discussed one aspect (e.g., PBL without digital modules, or digital modules without a PBL approach) were excluded. Through this multi-stage selection process, a final dataset of eligible articles was established for analysis.

Bibliometric analysis was conducted using VOSviewer software to map author collaboration networks, citation relationships, and keyword associations in the literature (van Eck & Waltman, 2010).The findings of the analysis are presented in the form of network visualizations, publication trend graphs, and productivity tables to reveal the structure of research development and identify dominant themes and future research opportunities in the integration of PBL and e-modules in physics education.

3. RESULTS AND DISCUSSION

3.1 Research Publication Trends

Publication trend analysis shows the number of studies on PBL and e-modules in physics education has increased

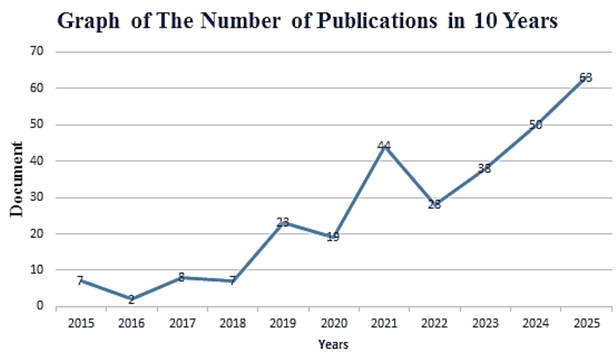


Figure 2. Graph of the number of publications in 10 years

significantly over the past decade.

In the initial period, 2015–2018, the number of articles published tends to be low and fluctuates in the range of 2 to 8 documents per year. An increase began in 2019 with 23 publications, followed by a slight decrease in 2020 to 19 publications. The most prominent spike occurred in 2021 with 44 publications, indicating increased research attention. Application of the PBL approach supported by digital learning in the context of physics education. Although there was a decrease in 2022 to 28 publications, the trend continued to increase consistently in the following years, with 38 publications in 2023, 50 publications in 2024, and reaching a peak in 2025 with 63 publications, as shown in Figure 2.

Based on Figure 2, the number of publications examining PBL and e-modules in physics education shows a significant upward trend over the past decade. Publication trends indicate a significant increase in studies on PBL and e-modules in physics education over the past decade. After a relatively low and fluctuating number of publications during 2015–2018, the trend began to rise in 2019 and reached its peak in 2025. Despite a slight decline in 2020 and 2022, the overall pattern shows consistent growth, reflecting increasing research interest in the integration of PBL and digital learning in physics education.

This increasing trend indicates that the integration of PBL and e-modules is increasingly viewed as a crucial approach in 21st-century physics learning (Kalonde et al., 2025). The sharp increase after 2020 indicates a strong push towards the implementation of problem-based learning supported by digital technology models (Donthu et al., 2021)This aligns with the need to develop critical thinking, problem-solving, collaboration, and digital literacy skills, which are the focus of modern education. The continued upward trend until 2025 also demonstrates that this topic is not a temporary phenomenon but is developing into a major focus in physics education research. Thus, the graph confirms a shift in research attention toward more contextual, interactive, and technology-based physics learning designs.

3.2 Distribution of Publication Types

The distribution of publication types in this study demonstrates the variety of forms of scientific dissemination used by researchers in examining PBL and e-modules in physics education. Based on Figure 3, conference papers account for 48% of the total publications, followed by journal articles at 47%, while conference reviews and book chapters each contribute 2%, review articles 1%, and books 0%. These figures indicate that conference papers and journal articles dominate the dissemination of research in this field, whereas other publication types make only a minor contribution. This pattern indicates that most research results in this field are disseminated through conference forums and scientific journals as the primary medium of academic

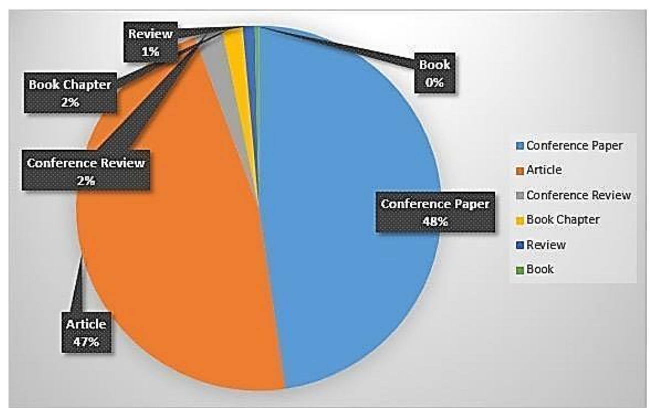


Figure 3. Percentage of publication types

communication.

The predominance of conference papers indicates that research on PBL and e-modules in physics education is developing dynamically and is often presented first at international scientific forums before being fully published in journals (Dwi Astutik et al., 2021). Conferences typically provide a faster and more flexible space for researchers to publish initial findings, particularly on rapidly evolving topics such as the integration of problem-based learning and digital technology. Furthermore, the high proportion of journal articles indicates that research in this area also has a strong scientific foundation and has undergone rigorous peer review. This combination of conference and journal publications reflects the balance between rapid dissemination and academic validation in the development of physics education research (Donthu et al., 2021)

Overall, the distribution of these publication types demonstrates that research related to e-module-assisted PBL is not only growing in quantity but is also actively discussed within the international scientific community. This pattern confirms that this field is progressive, responsive to developments in learning technology, and continues to mature through reputable scientific publications. These findings also demonstrate that studies on the integration of PBL and e-modules in physics education have become part of the global discourse in science education research.

3.3 Top Publication Sources

The most productive sources of scientific publications in research related to PBL and e-modules in physics education over the past ten years are presented in Table 1. The data shows that the Journal of Physics: Conference Series (JPCS) ranks first with a very dominant number of publications, namely 47 articles. This number far exceeds other publication sources, indicating that JPCS has become one of the main forums for researchers to publish study results in the realm of physics education and problem-based learning. This position indicates that the international conference proceedings forum still plays a significant role in the dissemination of science education research.

Table 1. Top 10 Journals Over the Last 10 Years

No	Author Name	Amount
1	Journal of Physics Conference Series	47
2	IEEE Transactions on Geoscience and Remote Sensing	8
3	Proceedings of SPIE the International Society Optical Enginnering	7
4	Aip Conference Proceedings	7
5	ASEE Annual Conference and Exposition Conference Proceedings	6
6	Communications in Computer and Information Science	5
7	ACM International Conference Proceeding Series	4
8	Physics Education	3
9	Lecture Notes in Computer Science Including Subseries Lecture Notes in Artifical Intelligence and Lecture Notes in Bioinformatics	3
10	IOP Conference Series Earth and Environmental Science	3

In general, these data indicate that research publications are dominated by conference proceedings and reputable international journals with broad scientific coverage. The dominance of the *Journal of Physics: Conference Series (JPCS)* indicates that conference proceedings play a major role in disseminating research in physics education. While JPCS is a reputable international conference proceeding indexed in major databases such as Scopus, it is important to note that conference publications generally undergo a different level of peer-review rigor compared to journal articles. Therefore, although JPCS provides a credible and accessible platform for the rapid dissemination of emerging research, the findings reported in such proceedings may still require further validation through publication in high-impact peer-reviewed journals.

3.4 Distribution of Fields of Science

The distribution of scientific fields provides an overview of the range of disciplines contributing to research related to the application of PBL and electronic modules in physics education. This analysis is important for understanding the trends in the most involved scientific fields and demonstrating the multidisciplinary nature of the research topics studied. The ten scientific fields with the highest number of publications in the last decade are shown in Table 2.

Table 2. Top 10 fields of science over the last 10 years

No	Field of Science	Amount
1	Physics and Astronomy	101
2	Engineering	96
3	Computer Science	91
4	Social Sciences	46
5	Mathematics	36
6	Earth and Planetary Sciences	25
7	Materials Science	19
8	Energy	17
9	Environmental Science	15
10	Multidisciplinary	7

Based on Table 2, research publications are dominated by the fields of Physics and Astronomy with 101 publications, followed by Engineering (96 publications) and Computer Science (91 publications). The dominance of these three fields indicates that research on PBL and e-modules in physics education focuses largely on developing understanding of physics concepts, problem solving, and the use of learning technology. Furthermore, the involvement of the fields of Engineering and Computer Science confirms the integration of pedagogical approaches, learning design, and digital technology. Overall, this distribution demonstrates that research on this topic is interdisciplinary and develops at the intersection of science, technology, and education.

3.5 Institutional Affiliation Distribution

Institutional affiliations provide an overview of institutions most actively contributing to research publications on PBL and e-modules in physics education. This analysis identifies the institutional centers that have been the primary drivers of research on these topics over the past ten years. The ten institutions that have the highest number of publications are shown in Table 3.

Table 3. Top 10 institutional affiliations over 10 years

No	Institution	Amount
1	Universitas Negeri Padang	10
2	Universitas Sebelas Maret	8
3	*Chinese Academy of Sciences*	7
4	*University of Chinese Academy of Sciences*	7
5	Universitas Negeri Yogyakarta	7
6	Universiti Pendidikan Sultan Idris	7
7	*Ministry of Education of the People's Republic of* China	6
8	Universitas Negeri Jakarta	6
9	*Nanyang Technological University*	5
10	*Zhejiang University*	4

Based on Table 3, the highest publication contribution came from Padang State University with 10 publications, followed by Sebelas Maret University (8 publications). Several other institutions, such as the Chinese Academy of Sciences, the University of Yogyakarta, and Sultan Idris University of Education, published seven publications. Contributions were also made by the Ministry of Education of the People's Republic of China and Jakarta State University, each of which contributed 6 publications, followed by Nanyang Technological University (5 publications) and Zhejiang University (4 publications). Overall, this distribution suggests that research on PBL and e-modules in physics education is concentrated in several countries, particularly China, the United States, and Indonesia, rather than being evenly distributed globally. The dominance of universities emphasizes the important role of higher education institutions in developing technology-based physics learning innovations.

3.6 Country Affiliation Distribution

The distribution of country affiliations shows the global distribution of research contributions related to PBL and e-modules in physics education. This analysis helps identify the countries most active in developing and disseminating research in these areas over the past ten years. The countries with the highest publication contributions are shown in Table 4.

Based on Table 4, China ranks first with 86 publications, followed by the United States (62 publications) and Indonesia (61 publications). Other countries such as Malaysia (12 publications) and Germany (11 publications) also show significant contributions, followed by Singapore and Canada (8 publications each), Hong Kong (7 publications), Italy (6 publications), and India (5 publications). Overall, this distribution indicates that research on PBL and e-modules in physics education is growing globally, with strong contributions from Asia and North America. The dominance of these countries reflects the support of higher education institutions, the development of technology-based educational research, and the increasing attention to innovation in science learning internationally.

Table 4. Top 10 country affiliations over the past 10 years

No	Country	Amount
1	China	86
2	*United States*	62
3	Indonesia	61
4	Malaysia	12
5	*Germany*	11
6	*Singapore*	8
7	Canada	8
8	Hong kong	7
9	*Italy*	6
10	*India*	5

4.3 Publication Authors

The findings in Figure 4 indicate that author productivity is spread across several researchers with relatively balanced contributions, without strong dominance by any one individual. This indicates that PBL and e-module research in physics education is developing collaboratively across various research groups. Although efforts were made during the initial screening to ensure metadata completeness, including the verification of author information, some records with incomplete metadata were retained to preserve the overall dataset size and trend representation. As a result, this study emphasizes general research trends and collective contributions rather than precise individual author productivity. Overall, these results confirm the broad academic community's support for the development of e-module-assisted PBL research.

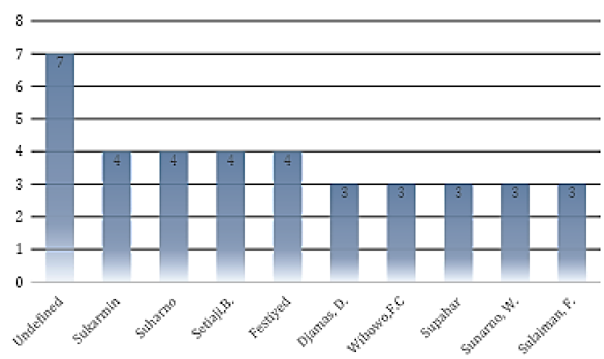


Figure 4. Shows the percentage of publication authors

Table. 5 Top Five Most of Cited Articles

No	Authors	Title	Source	Citation	Key Findings
1	Belbute-Peres, F.D.A., Allen, K.R., Smith, K.A., Tenenbaum, J.B., Zico Kolter, J.	End-to-end differentiable physics for learning and control	Advances in Neural Information Processing Systems, 2018-December, pp. 7178–7189	223	The integration of differentiable physics machines enables simultaneous learning of dynamics and control models, is more data-efficient, and results in more stable and accurate optimizations.
2	Jin, P., Zhang, Z., Zhu, A.,Tang, Y., Karniadakis,G.E.	End-to-end differentiable physics for learning and control	Advances in Neural Information Processing Systems, 2018-December, pp. 7178–7189	223	able to accurately model the dynamics of a Hamiltonian system while preserving its physical structure
3	Di Natale, L., Svetozarevic, B., Heer, P., Jones, C.N.	Physically Consistent Neural Networks for Building thermal modeling: Theory and analysis	Applied Energy, 325, 119806	101	PCNN is able to predict the thermal dynamics of buildings more accurately while remaining consistent with the laws of physics.
4	Qi, S., Wang, Y., Li, Y., Ren, Q., Ren, Y.	Two- Dimensional Electromagnetic Solver Based on Deep Learning Technique	IEEE Journal on Multiscale and Multiphysics Computational Techniques, 5, pp. 83–88, 9096576	92	Deep learning can predict 2-D electromagnetic fields with similar accuracy to classical methods, but much faster, making it suitable for real-time or high-resolution simulations.
5	Feng, S., Ji, K.,Wang, F., Ma, X., Kuang, G.	Electromagnetic Scattering Feature (ESF) Module Embedded Network Based on ASC Model for Robust and Interpretable SAR ATR	IEEE Transactions on Geoscience and Remote Sensing, 60,5235415	91	A neural network with an ASC-based ESF module improves SAR target recognition by exploiting the physical features of electromagnetic scattering, resulting in more accurate and stable predictions than conventional deep learning models.

3.7 Top 5 most cited articles

Table 5 displays the five articles ranked top based on the number of citations from all publications reviewed. These articles predominantly involve research integrating physics, learning systems, and computational approaches based on artificial intelligence, particularly machine learning and deep learning. The most highly cited articles discuss the development of differentiable physics models and physically consistent neural networks, demonstrating the strong interest in the scientific community in using modern computational methods to understand and model physical phenomena more accurately (Azer, 2017; Luckin & Cukurova, 2019).

The high number of citations indicates the significant contribution of these articles to scientific advancement, particularly at the intersection of physics, modeling, and technology-based learning systems. Furthermore, the predominance of publications in internationally reputable journals—such as Advances in Neural Information Processing Systems, Neural Networks, Applied Energy, and various IEEE journals—confirms that the most influential research still focuses on the development of advanced technology-based methods and models. To maintain alignment with the focus of this study, only articles that explicitly address PBL, e-modules, and their application in physics education were considered in the analysis. Articles that did not directly examine these aspects were excluded to ensure the relevance and validity of the findings. Given that the most cited articles primarily focus on computational and technology-based approaches rather than explicitly on PBL or e-modules, caution is needed in interpreting their relevance. These findings indicate general technological advancements in physics-related research, but do not directly confirm the potential or effectiveness of PBL and e-modules in physics education.

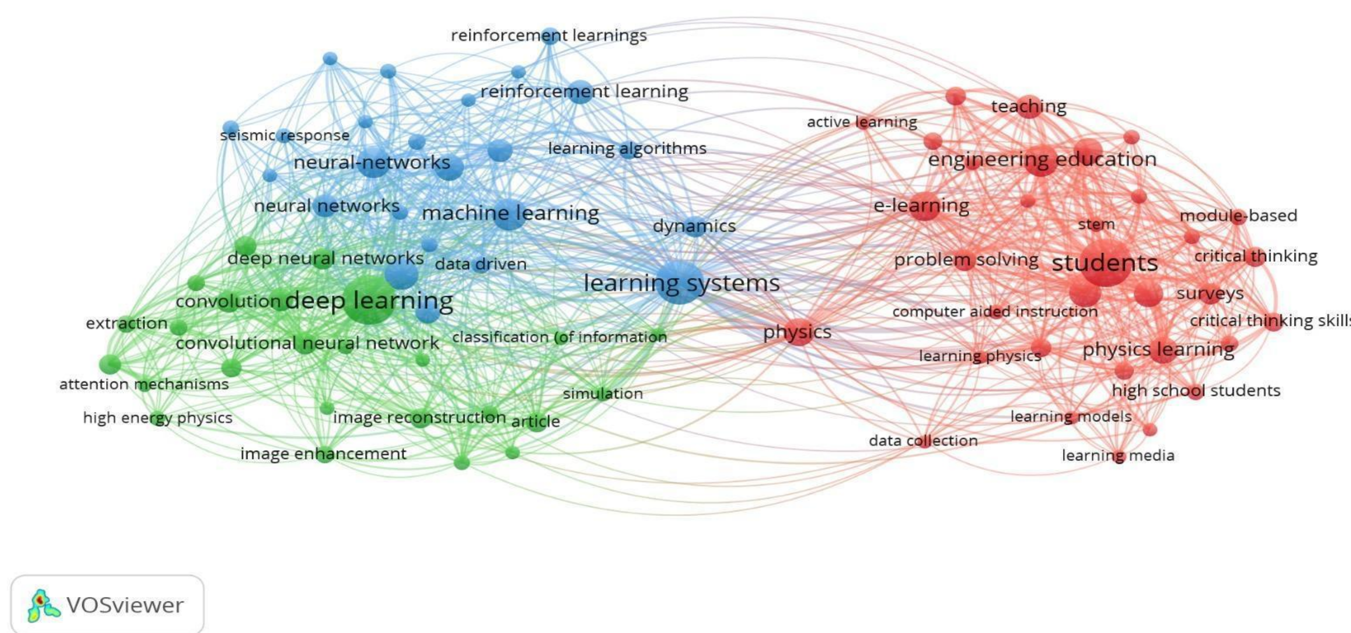


Figure 5. Visualization of Keyword Correlation Analysis

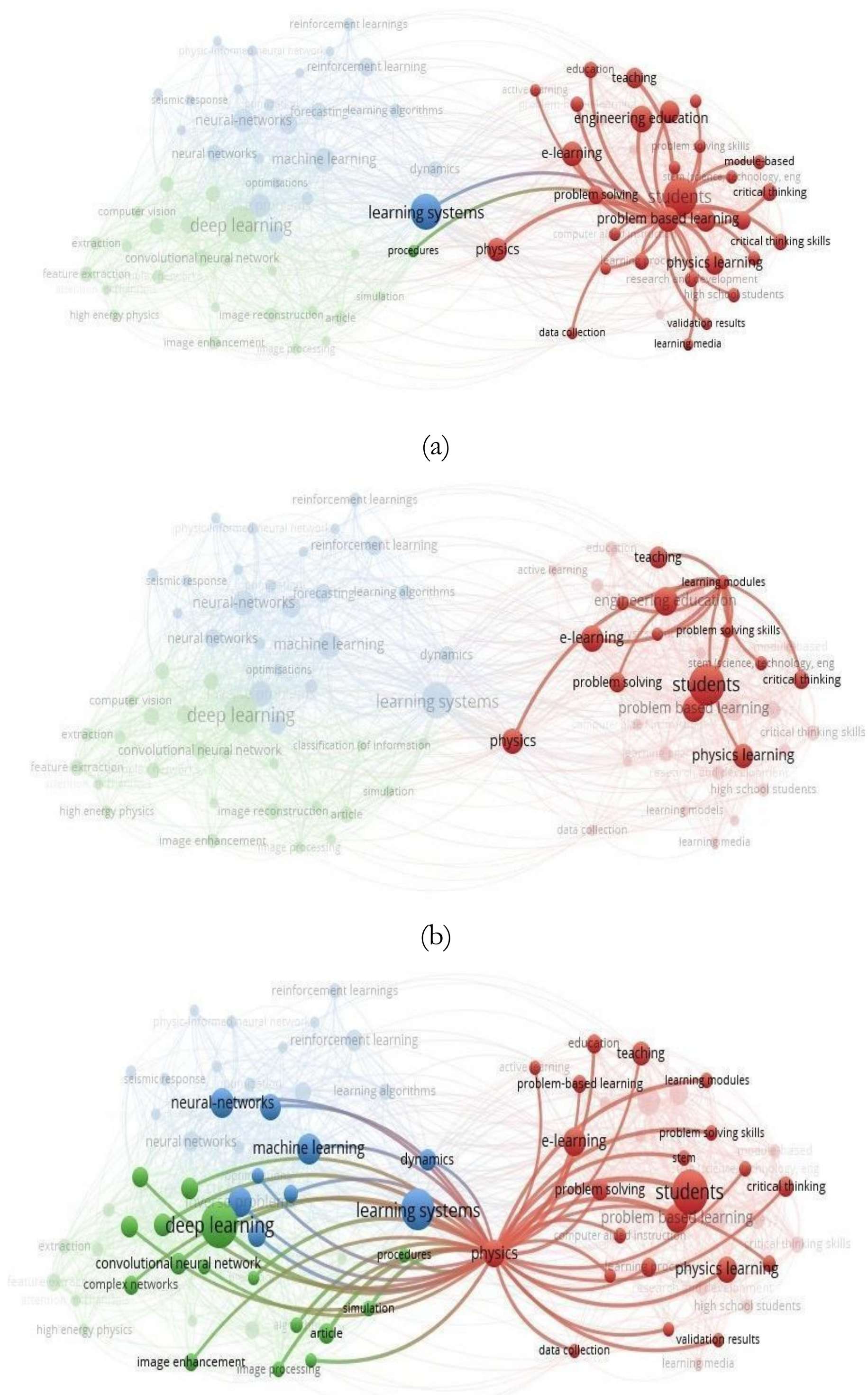
3.8 VOSviewer Analysis

A total of 281 articles were analyzed using VOSviewer to map research keywords and identify the interconnected themes and focuses of studies related to the implementation of PBL and the use of electronic-based physics modules (Suliyanah et al., 2021). The resulting visualization displays a network of research themes, revealing the relationships between PBL, e-modules, various learning outcomes, and pedagogical approaches frequently discussed in the publications. The findings of this study provide a comprehensive understanding of the current research development directions and thematic priorities in developing innovative learning strategies in physics education.

Figure 5 shows the mapping of the co-occurrence of keywords resulting from analysis using VOSviewer software. This network illustrates the conceptual structure of research related to PBL, learning modules, and physics education, based on the frequency of occurrence and relationships between keywords in the analyzed publications. The visualization results show several interconnected clusters, indicating that research in this area is organized into several interrelated main themes. One prominent cluster is dominated by keywords related to PBL, including problem-solving skills, critical thinking skills, and a learning approach that places students at the center of the learning process. This finding confirms that PBL is consistently positioned as a pedagogical approach that encourages strengthening high-level thinking skills and increasing student activity in learning (Ali, 2019; Branch, 2004; Schmidt et al., 2011)

Another major cluster focuses on learning modules and digital learning, characterized by keywords such as e-module, digital learning, and learning media. This reflects the increasingly important role of digital learning resources in supporting PBL implementation, particularly in technology-integrated learning environments (Alviz-Meza et al., 2022; Zhang et al., 2022) The strong link between PBL and digital learning keywords demonstrates a trend toward integration between pedagogical and technological aspects in the physics education literature, emphasizing a research direction that combines methodological innovation with the use of learning technologies.

Figure 6 presents a more detailed visualization of the keyword network based on the three main research variables: (a) PBL, (b) learning modules, and (c) physics. This visualization highlights the relationship structure between keywords within each variable as well as their interrelationships across domains. In the PBL network (Figure 6a), keywords such as problem-solving, students, and learning outcomes emerge as key nodes, indicating that PBL research places significant emphasis on student learning outcomes, particularly cognitive aspects and problem-solving skills (Anazifa & Djukri, 2017; Huang et al., 2021) Meanwhile, the learning module network



(a)

(b)

c)

Figure 6. Visualization of Keyword Correlation Analysis

(Figure 6b) demonstrates a strong relationship between learning modules, digital learning, and learning media, indicating that learning modules are increasingly conceptualized as digital learning resources that support independent and structured learning processes in PBL environments (Hmelo-Silver, 2004). The physics network (Figure 6c) shows that research in physics frequently links PBL and learning modules with keywords such as concept understanding, critical thinking, and physics learning. Although physics appears as a relatively separate cluster, its significant association with PBL and learning modules underscores the growing interest in integrating active

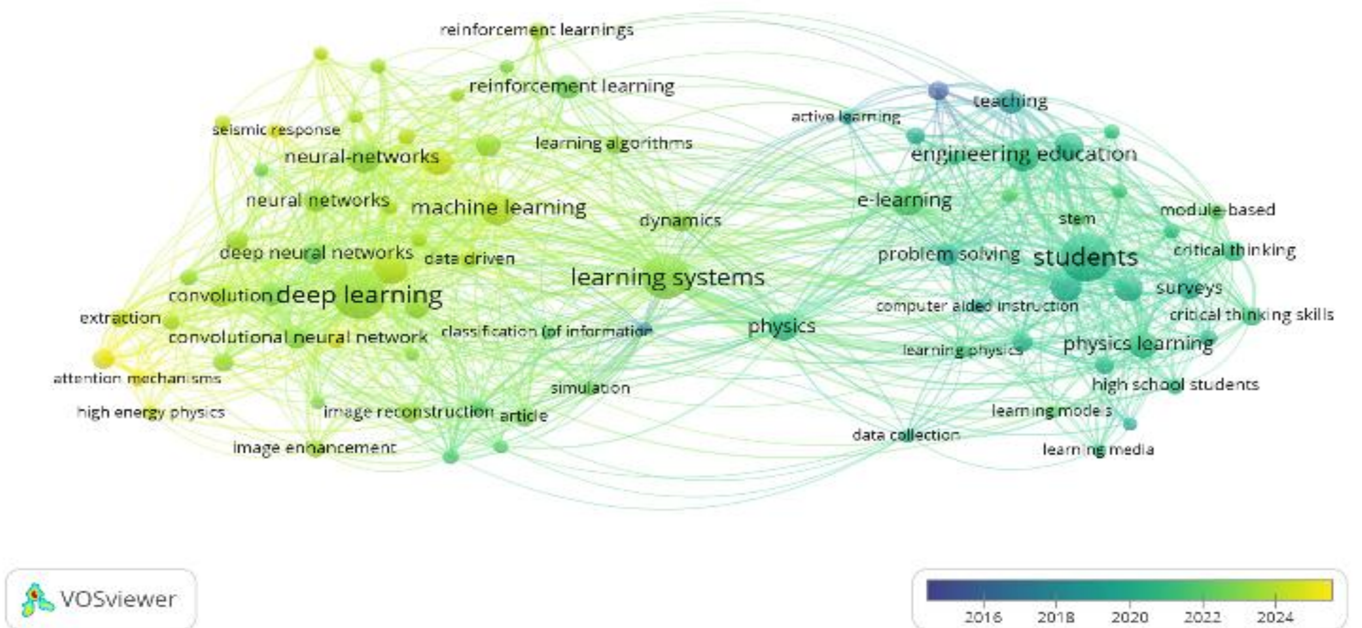


Figure 7. Overlay Visualization

learning models and digital learning resources in physics education.

Overall, this network visualization demonstrates that while each variable has been extensively studied separately, research explicitly integrating PBL, digital modules, and physics education remains relatively limited. This indicates significant research opportunities for further study (Sulhiyah, 2025).

Figure 7 shows a map of the development and direction studies focusing on PBL and e-modules in physics education over the last decade, based on the results of bibliometric analysis. The overlay visualization shows a shift in research focus from early topics dominated by computational and algorithmic approaches, indicated by blue to teal, to newer themes, indicated by green to yellow. In the early phase, research focused heavily on machine learning, deep learning, and neural networks, reflecting studies on the use of computational technologies in physics learning and simulation system development (Goos et al., 2021; Handoyo & Safran, 2025).

Over time, the focus of research has shifted significantly to the realm of physics education, marked by the emergence of keywords such as students, physics learning, problem solving, critical thinking, e-learning, and engineering education . The shift toward yellow indicates the increasing intensity of recent research emphasizing the implementation of e-module-based PBL and digital learning to improve students' critical thinking skills. This development began to be seen significantly around 2019 and intensified in the 2020–2022 period, triggered by the impact of the COVID-19 pandemic, which encouraged innovation in interactive e-modules, online learning, and problem-based learning systems that are appropriate to the characteristics of physics learning .

Overall, this map indicates that the future direction of PBL and e-module research in physics education tends to integrate problem-based pedagogical approaches with digital and computing technologies. Future research trends could potentially focus on the development of adaptive e-modules, the integration of artificial intelligence in physics learning, and the strengthening of critical thinking and problem-solving skills as key competencies for the 21st century (Garzón et al., 2020).

Figure 8 displays a visualization of keyword density, representing the intensity and focus of the study regarding the application of PBL and e-modules in physics education. In this map, lighter colors indicate keywords with higher frequency of occurrence and strong links to scientific publications. Keywords such as students, physics learning, problem solving, and critical thinking appear most dominant, indicating that e-module-based PBL research consistently places students at the center of the learning process and focuses on developing higher-order cognitive skills (Howard et al., 2021).

Furthermore, the high intensity of the appearance of keywords such as e-learning, active learning, teaching, and engineering education indicates that the implementation of PBL in physics education is increasingly geared toward strengthening active learning and utilizing digital technology (Zawacki-Richter et al., 2019). This finding underscores the role of e-modules as learning media that support problem-solving, exploration of physics concepts, and development of students' critical thinking skills (Puspa et al., 2021; Sutarmi & Suarjana, 2017).

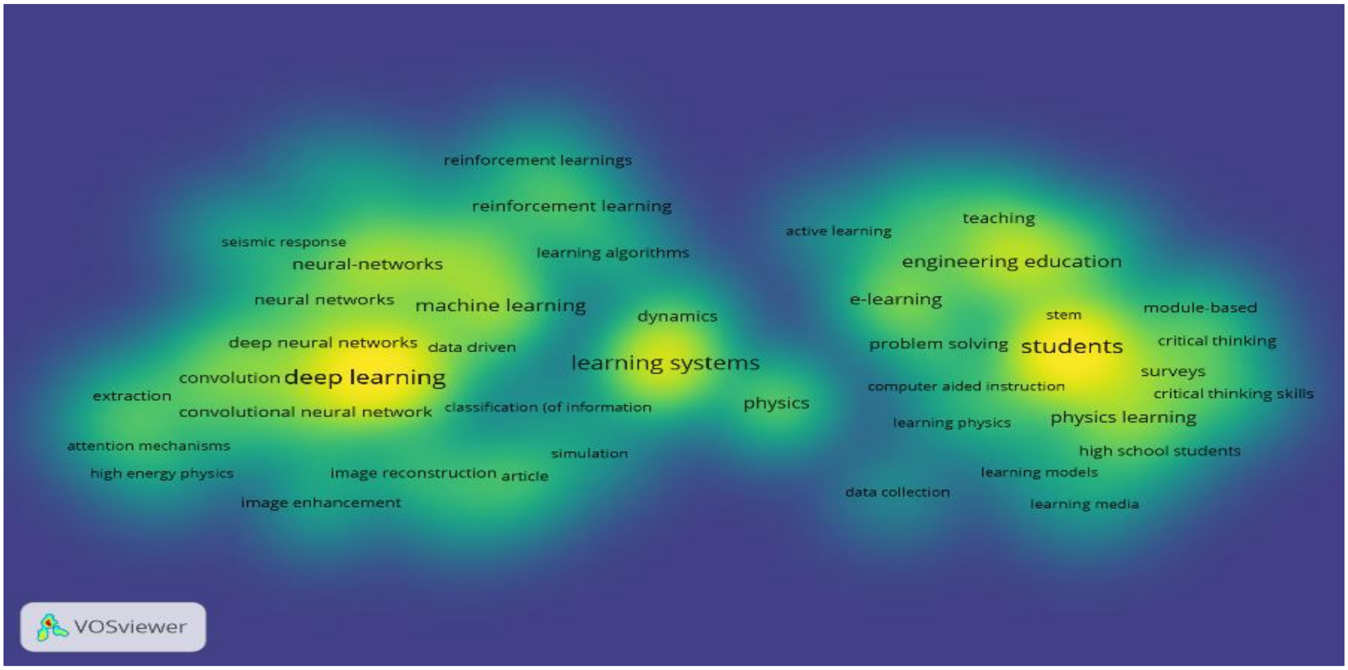


Figure 8. Density Visualization

In addition, the relationship between educational keywords and computing terms such as learning systems and simulations opens up opportunities for future research to integrate PBL, interactive e-modules, and technology-based approaches. Overall, this density map suggests that future research should focus on developing PBL-based physics learning supported by digital e-modules, with the goal of creating a learner-centered learning experience, increasing cognitive engagement, and strengthening critical thinking and problem-solving skills (Belay et al., 2023; Hidayati et al., 2024; Hinojo-Lucena et al., 2019).

DISCUSSION

The findings of the bibliometric analysis provide a comprehensive understanding of research trends related to PBL, e-modules, and physics education over the past ten years. The increase in the number of publications, particularly after 2019, indicates growing academic interest in learner-centered learning models and the use of digital learning resources, in line with the global educational transformation that demands mastery of critical thinking and problem-solving skills (Alviz-Meza et al., 2022; Donthu et al., 2021)The dominance of proceedings and journal articles demonstrates the dynamics of research: proceedings serve as the initial space for learning innovation, while journals represent more mature and methodologically sound empirical research (Azer, 2017; Suprapto et al., 2021).

Keyword correlation analysis confirms that PBL remains a primary pedagogical framework, with strong links to problem solving, critical thinking, and learner-centered learning. Keywords such as students, physics learning, and problem solving indicate a focus on developing students' higher-order cognitive skills, while PBL's association with e-learning, active learning, and learning media underscores the role of e-modules as scaffolding to support independent learning and exploration of physics concepts (Alviz-Meza et al., 2022; Zhang et al., 2022)

The visualization of the development map and keyword density shows a shift in research focus from computational topics (machine learning, deep learning) to pedagogical themes based on PBL and e-modules (students, physics learning, critical thinking). This shift has intensified since 2019–2022, triggered by the COVID-19 pandemic, which has driven innovation in interactive e-modules, online learning, and technology-based PBL systems (Riyadi et al., 2025). However, physics education still plays a more application-focused role than an analytical focus, indicating the need for deeper exploration of the conceptual challenges unique to physics, such as changes in conceptions, representation of phenomena, and scientific reasoning (Suwastini et al., 2021).

The novelty of this research lies in its integrative focus on PBL, e-modules, and physics education, differing from previous studies that tend to examine each aspect separately. This finding opens up opportunities for the development of adaptive and interactive e-modules that utilize digital technology and AI, emphasize active learning, and strengthen critical thinking and problem-solving skills as key 21st-century competencies. Furthermore, this study highlights the need for longitudinal studies and systematic synthesis to build a more robust theoretical framework in PBL-based physics education, so that pedagogical innovation can align with the conceptual needs of the discipline (Luciani et al., 2024; Musa'ad et al., 2024; Musridannur, 2025).

4. CONCLUSION

Findings: This bibliometric study reveals a significant increase in research related to PBL and e-modules in physics education over the last decade, particularly after 2019. The findings indicate that PBL has consistently been the dominant pedagogical approach, with strong links to problem-solving skills, critical thinking, and learner-centered learning. Meanwhile, e-modules have emerged as important digital learning tools, supporting PBL implementation by providing a structured, flexible learning environment and encouraging independent learning. However, physics education is often positioned as a context of application, rather than the primary focus of analysis, indicating that the integration of PBL and e-modules specific to the physics discipline remains relatively limited

Implications: The results of this study are relevant and meaningful for the research community, education practitioners, and curriculum developers. For researchers, the findings emphasize the need for studies that not only assess general pedagogical effectiveness but also focus on specific physics learning outcomes, such as concept mastery and scientific reasoning skills. For educators, the integration of PBL with systematically designed digital e-modules offers a promising strategy for increasing student engagement and higher-order thinking skills in physics learning. Meanwhile, for curriculum developers, this study emphasizes the urgency of adapting learning design to the epistemological characteristics of physics, so that meaningful and sustainable learning outcomes are achieved

Research Limitations: Despite its significant contribution, this study has several limitations. First, the bibliometric analysis is based entirely on published data indexed in international databases, specifically Scopus and Web of Science, which may result in the exclusion of relevant studies published in local or non-indexed journals. Second, the analysis focused on bibliographic metadata, rather than the full text, thus limiting the depth of interpretation regarding pedagogical implementation and learning effectiveness. Third, differences in keyword usage across publications may impact the completeness of the research theme mapping .

Directions for Further Research: Based on these limitations, further research is recommended to conduct an empirical study that specifically assesses the effectiveness of the approach in the context of physics learning PBL-based e-modules, particularly on students' conceptual mastery, critical thinking skills, and problem-solving abilities. Furthermore, longitudinal and mixed-method research designs are necessary to conduct a study on the long-term impact of implementing a digital-based PBL learning environment. Future bibliometric studies can also expand data sources and integrate content analysis to gain a more comprehensive insight into the development of research and learning innovation in the field of physics education.

REFERENCES

Ali, S. S. (2019). Problem Based Learning: A Student-Centered Approach. *English Language Teaching*, *12*(5), 73. https://doi.org/10.5539/ELT.V12N5P73

Alviz-Meza, A., Vásquez-Coronado, M. H., Delgado-Caramutti, J. G., & Blanco-Victorio, D. J. (2022). Bibliometric analysis of fourth industrial revolution applied to heritage studies based on web of science and scopus databases from 2016 to 2021. *Heritage Science 2022 10:1*, *10*(1), 189-. https://doi.org/10.1186/s40494-022-00821-3

Anazifa, R. D., & Djukri. (2017). Project- based learning and problem- based learning: Are they effective to improve student's thinking skills? *Jurnal Pendidikan IPA Indonesia*, *6*(2), 346–355. https://doi.org/10.15294/JPII.V6I2.11100

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975. https://doi.org/10.1016/J.JOI.2017.08.007

Ariantini, K. P., Suwastini, N. K. A., Adnyani, N. L. P. S., Dantes, G. R., & Jayantini, I. G. A. S. R. (2021). Integrating Social Media into English Language Learning: How and to What Benefits According to Recent Studies. *NOBEL: Journal of Literature and Language Teaching*, *12*(1), 91–111. https://doi.org/10.15642/NOBEL.2021.12.1.91-111

Azer, S. A. (2017). Top-Cited Articles in Problem-Based Learning: A Bibliometric Analysis and Quality of Evidence Assessment. *Journal of Dental Education*, *81*(4), 458–478. https://doi.org/10.21815/JDE.016.011

Bashir, F., & Warraich, N. F. (2023). Systematic literature review of Semantic Web for distance learning. *Interactive Learning Environments*, *31*(1), 527–543. https://doi.org/10.1080/10494820.2020.1799023

Belay, F., Berhane, D., Teshale, H., Mulubrhan, G., Hagos, T., Gebremariam, H., Brhane, T., & Islam, Z. (2023). The effect of war on educational institutions of Eastern Tigray zone, Tigray state, Ethiopia. *International Journal of Educational Development*, *102*, 102864. https://doi.org/10.1016/J.IJEDUDEV.2023.102864

Branch, W. A. (2004). The Theory of Rationally Heterogeneous Expectations: Evidence from Survey Data on Inflation Expectations. *Economic Journal*, *114*(497), 592–621.

https://ideas.repec.org/a/ecj/econjl/v114y2004i497p592-621.html

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/J.JBUSRES.2021.04.070

Dwi Astutik, R., Niswati, M., & Jauhariyah, R. (2021). Studi Meta Analisis Problem Based Learning dalam Pembelajaran Fisika. *Orbita*, *7*(1), 159–168. https://doi.org/10.31764/ORBITA.V7I1.4525

Ernawati, E., & Rahmawati, R. (2021). Application of Problem Based Learning Model to Mathematical Thinking Ability. *EduMa: Mathematics Education Learning and Teaching*, *10*(2), 187–197. https://doi.org/10.24235/EDUMA.V10I2.9060

Fullan, M., Mackay, T., Redman, K., Cropley, M., & Miller, A. (2021). *The right drivers for whole system success CSE LEADING EDUCATION SERIES*. The Cntre for Strategic Education. https://michaelfullan.ca/wp-content/uploads/2021/03/Fullan-CSE-Leading-Education-Series-01-2021R2-compressed.pdf

Garzón, J., Kinshuk, Baldiris, S., Gutiérrez, J., & Pavón, J. (2020). How do pedagogical approaches affect the impact of augmented reality on education? A meta-analysis and research synthesis. *Educational Research Review*, *31*, 100334. https://doi.org/10.1016/J.EDUREV.2020.100334

Goos, M., Pipa, J., & Peixoto, F. (2021). Effectiveness of grade retention: A systematic review and meta-analysis. *Educational Research Review*, *34*, 100401. https://doi.org/10.1016/J.EDUREV.2021.100401

Handoyo, W. S., & Safran, S. (2025). Enhancing Problem-Solving Skills on Ethnic Diversity Through Problem-Based Learning in Fifth-Grade Students. *Journal of Social Work and Science Education*, *6*(3), 1088–1097. https://doi.org/10.52690/JSWSE.V6I3.1251

Hidayati, I. N., Berliana, C. I., & Zaman, B. (2024). Penerapan Metode Problem Based Learning dalam Meningkatkan Berfikir Kritis Pada Pembelajaran PAI. *Journal of Instructional and Development Researches*, *4*(6), 540–550. https://doi.org/10.53621/JIDER.V4I6.418

Hinojo-Lucena, F. J., Aznar-Díaz, I., Cáceres-Reche, M. P., & Romero-Rodríguez, J. M. (2019). Artificial Intelligence in Higher Education: A Bibliometric Study on its Impact in the Scientific Literature. *Education Sciences 2019, Vol. 9, Page 51*, *9*(1), 51. https://doi.org/10.3390/EDUCSCI9010051

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review*, *16*(3), 235–266. https://doi.org/10.1023/B:EDPR.0000034022.16470.F3/METRICS

Howard, S. K., Tondeur, J., Ma, J., & Yang, J. (2021). What to teach? Strategies for developing digital competency in preservice teacher training. *Computers & Education*, *165*, 104149. https://doi.org/10.1016/J.COMPEDU.2021.104149

Huang, C. J., Thirumalraj, B., Tao, H. C., Shitaw, K. N., Sutiono, H., Hagos, T. T., Beyene, T. T., Kuo, L. M., Wang, C. C., Wu, S. H., Su, W. N., & Hwang, B. J. (2021). Decoupling the origins of irreversible coulombic efficiency in anode-free lithium metal batteries. *Nature Communications 2021 12:1*, *12*(1), 1452-. https://doi.org/10.1038/s41467-021-21683-6

Kalonde, G., Boateng, S., Duedu, C., Kalonde, G., Boateng, S., & Duedu, C. (2025). Artificial Intelligence in Classroom Assessment: Opportunities, Equity Challenges, and Best Practices for Formative and Summative Integration. *Open Access Library Journal*, *12*(9), 1–16. https://doi.org/10.4236/OALIB.1114121

Luciani, M., Barisone, M., Bentivegna, M., Fioremisto, A., Galeazzi, G., La Monica, M. A., Musci, A., Ausili, D., & Dal Molin, A. (2024). Italian Nursing Research: A Bibliometric Analysis from 1980 to 2020. *Nursing Reports*, *14*(4), 3933–3942. https://doi.org/10.3390/NURSREP14040287/S1

Luckin, R., & Cukurova, M. (2019). Designing educational technologies in the age of AI: A learning sciences-driven approach. *British Journal of Educational Technology*, *50*(6), 2824–2838. https://doi.org/10.1111/BJET.12861

Musa'ad, F., Ahmad, R. E., Sundari, S., & Hidayani, H. (2024). Pembelajaran Berbasis Proyek untuk Meningkatkan Kemampuan Berpikir Kritis Siswa. *Jurnal Cendekia : Jurnal Pendidikan Matematika*, *8*(2), 1481–1487. https://doi.org/10.31004/CENDEKIA.V8I2.3361

Musridannur. (2025). Implementation of Problem Based Learning Model to Improve Student Learning Outcomes in Islamic Education Learning at SD Negeri 341 Batahan. *Jurnal Cendekia Islam Indonesia*, *1*(1), 404–418. https://doi.org/10.62945/JCII.V1I1.130

OECD. (2022). OECD Economic Outlook, Volume 2022 Issue 2: Confronting the Crisis. *OECD Economic Outlook, OECD Economic Outlook*, *2022*(2). https://doi.org/10.1787/F6DA2159-EN

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, *372*. https://doi.org/10.1136/BMJ.N71

Puspa, V. R., Hidayat, T., & Supriatno, B. (2021). Development of android-based digital determination key application (e-KeyPlant) as learning media for plant identification. *Journal of Physics: Conference Series*, *1806*(1), 012145. https://doi.org/10.1088/1742-6596/1806/1/012145

Riyadi, S., Fauziah, N., 2b, A., Ningtyas, D. A., Widiyanah, I., & Bachri, S. (2025). Implementasi Pendekatan Deep Learning dalam Peningkatan Kualitas Pembelajaran di Sekolah Dasar Darul Ilmi Surabaya. *Paradigma: Jurnal Filsafat, Sains, Teknologi, Dan Sosial Budaya*, *31*(2), 648–653. https://doi.org/10.33503/PARADIGMA.V31I2.2598

Sari, M., & Rosidah, A. (2023). Implementasi Model Pembelajaran Problem Based Learning (PBL) Terhadap Hasil Belajar IPS SD. *Jurnal Ilmiah Pendidik Indonesia*, *2*(1), 8–17. https://doi.org/10.56916/JIPI.V2I1.307

Sarıkaya, Ö., & Çeliker, H. D. (2024). A Bibliometric Analysis of Publications on Problem- Based Learning. *Bartın University Journal of Faculty of Education*, *13*(3), 453–466. https://doi.org/10.14686/BUEFAD.1088208

Schmidt, H. G., Rotgans, J. I., & Yew, E. H. J. (2011). The process of problem-based learning: What works and why. *Medical Education*, *45*(8), 792–806. https://doi.org/10.1111/J.1365-2923.2011.04035.X;PAGE:STRING:ARTICLE/CHAPTER

Smarandache, I. G., Maricutoiu, L. P., Ilie, M. D., Iancu, D. E., & Mladenovici, V. (2022). Students' approach to learning: evidence regarding the importance of the interest-to-effort ratio. *Higher Education Research & Development*, *41*(2), 546–561. https://doi.org/10.1080/07294360.2020.1865283

Sulhiyah, S. (2025). Research Trends of Problem Based Learning (PBL) Based E-Modules to Improve Students' Science Process Skills in Science Learning: Bibliometric Analysis (2015-2024). *International Journal of Science Education and Science*, *2*(2), 144–152. https://doi.org/10.56566/IJSES.V2I2.265

Suliyanah, Adelia, B. D., Jauhariyah, M. N. R., Misbah, Mahtari, S., Saregar, A., & Deta, U. A. (2021). A bibliometric analysis of minimum competency assessment research with VOS viewer related to the impact in physics education on 2019-2020. *Journal of Physics: Conference Series*, *2110*(1). https://doi.org/10.1088/1742-6596/2110/1/012022

Suprapto, N., Prahani, B. K., & Cheng, T. H. (2021). Indonesian curriculum reform in policy and local wisdom: Perspectives from science education. *Jurnal Pendidikan IPA Indonesia*, *10*(1), 69–80. https://doi.org/10.15294/JPII.V10I1.28438

Sutarmi, K., & Suarjana, I. M. (2017). Peningkatan Hasil Belajar Siswa Menggunakan Metode Problem Solving dalam Pembelajaran. *Jurnal Ilmiah Sekolah Dasar*, *1*(2), 75–82. https://doi.org/10.23887/JISD.V1I2.10141

Suwastini, N. K. A., Puspawati, N. W. N., Adnyani, N. L. P. S., Dantes, G. R., & Rusnalasari, Z. D. (2021). Problem-based learning and 21st-century skills: Are they compatible? *EduLite: Journal of English Education, Literature and Culture*, *6*(2), 326–340. https://doi.org/10.30659/E.6.2.326-340

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/S11192-009-0146-3

Yew, E. H. J., & Goh, K. (2016). Problem-Based Learning: An Overview of its Process and Impact on Learning. *Health Professions Education*, *2*(2), 75–79. https://doi.org/10.1016/J.HPE.2016.01.004

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education – where are the educators? *International Journal of Educational Technology in Higher Education 2019 16:1*, *16*(1), 39-. https://doi.org/10.1186/S41239-019-0171-0

Zhang, L., Lin, X., Wang, Y., & Liu, Y. (2022). Sleep quality in patients with gastroesophageal reflux disease: A polysomnographic study. *Journal of Neurogastroenterology and Motility*, *28*, 289–297.