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Implementation of the Problem Based Learning Model in Science Education: Trend and Opportunity of Research Using Systematic Literature Network Analysis

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Abstract: The purpose of this study is to describe research trend data related to the implementation of PBL in science education. Article metadata was collected from the SCOPUS database, and 131 relevant articles were selected in 2013-2022. Data were analyzed using the Systematic Literature Network Analysis (SLNA) method with the VOSViewer application. Variables of bibliometric analysis, such as the number of articles and citations each year, the journals and authors with the most publications, countries, and networks of authors' cooperation, were determined based on metadata and analyzed descriptively. This research shows that the number of PBL research articles in science education during the 2013-2022 period fluctuated and tended to increase. The top keywords with the highest link strength are science, teacher, and technology. Recent research focuses on modules/e-modules, scientific literacy, natural science, and physics as important keywords. Future research related to the use of PBL learning has the potential to be developed in physics material and focuses on developing 21st-century skills such as creative thinking, critical thinking, communication, and collaboration. In addition, further research can focus on developing the knowledge and skills of prospective teachers in implementing PBL models that are integrated with 21st-century skills.

Keywords: bibliometric; problem-based learning; science education.

Introduction

Problem-Based Learning (PBL) is an innovative learning model that can improve the quality of education from the elementary to the tertiary level through an emphasis on problem-solving and higher-order thinking (Amin et al., 2020; Anggraeni et al., 2023). PBL is not a new model and was first developed by Barrows in the study of medical science in the 1960s. The development of PBL then penetrated other disciplines, such as social sciences, business education, architecture, engineering, and science education. John Dewey introduced PBL in education. According to Dewey (Shishigu et al., 2018), in problem-based learning, there is an interaction between stimuli and responses in the learning environment. Relevant problems are introduced at the beginning of the learning cycle, which provide context and motivation in subsequent learning. Dewey assumed that learning through problem-solving, critical thinking, and action would make learning better than memorizing facts.

Problem-based learning (PBL) has influenced various fields over the last half-century, both in higher education and schools (Anggraeni et al., 2023). The results of PBL implementation show that PBL is an effective classroom teaching method that encourages active and meaningful learning in students. Over the past half century, researchers have demonstrated that PBL can be practically useful in enhancing students' cognitive skills and attitudes towards learning (Fidan & Tuncel, 2019). PBL is effective in improving problem-solving skills (Simanjuntak et al., 2021; Khoiriyah &

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Husamah, 2018, critical thinking (Ismail et al., 2018; Amin et al., 2020; Anggraeni et al., 2023), creative thinking (Yaman & Yalçın, 2020; Wartono et al., 2018; Khoiriyah & Husamah, 2018), and communication (Jdaitawi, 2020; Miner-Romanoff et al., 2019; Khodijah, 2018). In addition, PBL can facilitate learners for lifelong learning through the development of self-regulation, inquiry, and metacognition. In other words, PBL does not only emphasize the acquisition of knowledge and skills, but also trains students to apply knowledge and skills in the real world or authentic contexts.

In reviewing research on PBL, most of the research focuses on the effectiveness of PBL implementation (Shishigu et al., 2018), PBL implementation problems (Fadillah et al., 2019) such as perceptions students, tutor role, group processing skills and learning PBL problem design. The evolution of the knowledge base in problem-based learning based on bibliometric results conducted by Hallinger (2021) shows that publications about PBL have continued to increase over the past ten years (2010-2019), and most of them have been implemented in the medical/health education sector. The bibliometric results also show that PBL research is starting to shift towards learning student satisfaction, self-directed learning, self-efficacy, collaboration, and critical thinking.

It appears that several scientific contributions related to PBL in various fields have been made but as far as we know, research that specifically discusses in depth the current PBL research trends in the field of science learning has not been carried out. Even though the implementation of PBL in science learning has a special place in the curriculum, especially in Indonesia. Many science education researchers carry out PBL learning innovations to improve students' science learning achievement. PBL is constructivism-based learning (Kuvac & Koc, 2018) which can increase conceptual understanding, help students apply physics principles well when learning, increase learning motivation (Shishigu et al., 2018), increase metacognitive awareness (Kuvac & Koc, 2018), improve critical thinking skills and care for the environment (Aufa, et al., 2021). Therefore, to see new innovation opportunities in PBL research in the field of science education can be done by means of Systematic Literature Network Analysis (SLNA) (Khitous et al., 2020).

Systematic Literature Network Analysis (SLNA) is a method for obtaining accurate and relevant data with a broader range. SLNA is a combination of Systematic Literature Review (SLR) and Bibliographical Analysis (BA), which aims to find and identify all material relevant to the topic to be studied systematically or following a set of procedures (Wahyudi et al., 2023). SLR identify where little or no relevant research has been conducted, necessitating new primary research. Traditionally in education, Newman & Gough (2020) revealed that literature reviews are useful in making claims regarding a known and unknown phenomenon, subject or topic, thereby opening up new research opportunities in education and teaching. A quantitative analytical method that reveals the bibliographical features of the literature is called BA. The bibliometric method is based on the principle of obtaining a general view of the subject area studied with bibliographic data obtained from databases and is mostly carried out for two purposes, namely performance analysis and scientific mapping. In bibliographic analysis, the performance of scientific publications of institutions or countries is determined, while scientific mapping reveals dynamics in scientific fields and the structure of these dynamics.

Various tools such as quantitative bibliometrics, algorithms and software are implemented in SLNA. The result is a dynamic picture of the progress of research on the implementation of PBL in science education from time to time. The purpose of this study is to describe research trend data related to the implementation of PBL in the field of science education. The research questions are: 1) How are the citations of PBL publications and research articles in science education developed over time from 2013 to 2022?; 2) Who are the most influential authors and countries in the publication of articles on PBL in science education from 2013 to 2022?; 3) What are the most relevant keywords, and what patterns of occurrence can be found on the topic of PBL in science education? The results of this publication will contribute to finding topics that have been researched and useful for directing future studies of PBL in science education.

Method

This paper assesses the academic publications on PBL research in science education available in the Scopus bibliographical database (Goli & Haghighinasab, 2022; Khitous et al., 2020; Thu et al., 2021). The Scopus database is declared as the largest database and is estimated to be 60% larger than the Web of Science (WoS) database (Khitous et al., 2020; Supriadi et al., 2020). More than 77.8 million core records are contained in the Scopus database from various fields with various metadata and document types, both non-academic and academic fields (Nurdin et al., 2021; PhamDuc et al., 2021; Singh et al., 2021).

The articles in this study were selected and analyzed using the Systematic Literature Network Analysis (SLNA) method (Figure 1), which consists of two stages, namely SLR and BA. SLR to describe the scope of research and produce papers that are used as

input for the next step. SLR stages (Colicchia et al., 2019) include stages; 1) Scope of the analysis, to formulate research questions and to frame the correct literature review; 2) Locating Studies ("keywords, time, document type, language") using the Scopus database, 3) Selecting the body of literature using the criteria to use/not use the article. The output of this stage is a collection of selected articles to be analyzed in the next stage. Stages of Bibliographical Analysis and Visualization to describe emerging research trends using Citation Network Analysis and Keyword Co-occurrence Network.

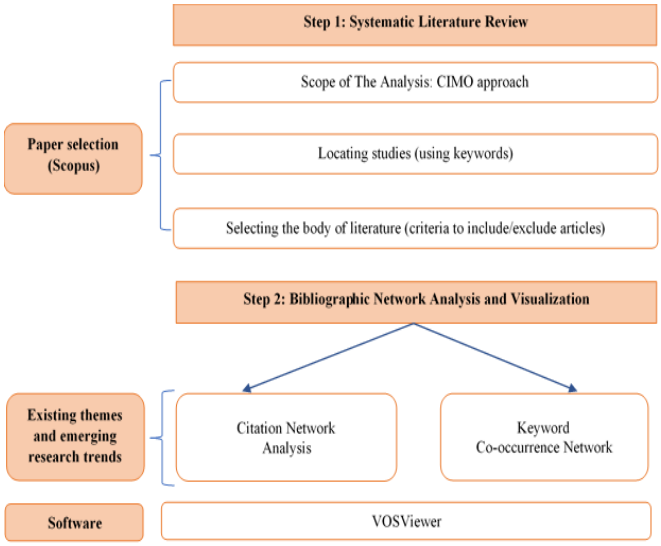

Figure 1. Steps and software used for the SLNA

Data collection took place on January 19, 2023. For Data collection took place on January 19, 2023. For paper searches, a general set of criteria has been defined regarding recognized data, which includes the use of keywords in concurrence with binary operators such as "OR, AND, and AND-NOT". In addition, we limited data assembly to research published in 2013-2022 periode, and papers published in journals and proceedings and written in English.

The results are sorted by "number of citations" from high to low. Then, it was filtered again by checking one by one the papers that were relevant to the research objectives. Then the data results were taken in .csv and .ris file formats and uploaded to the VOSViewer software to display details of data transcription and visualize bibliometric assignments (Abdullah, 2022; Effendi et al., 2021; Williams, 2020). For the final phase, the data were investigated descriptively to answer the research aims.

Result and Discussion

Results of Systematic Literature Review
Scope of the analysis

This stage aims to state the research scope analyzed to avoid ambiguity in the review (Wahyudi et al., 2023). The approach used in determining the scope of papers to be analyzed is the CIMO approach, which includes Context, Intervention, Mechanism, and Outcome. 1) Context: The papers to be analyzed are research papers in the situation of PBL implementation in science education. 2) Intervention: the scope of intervention in the papers analyzed are papers related to implementing PBL in science learning. 3) Mechanisms: mechanisms according to the treatment given and related to the learning strategies in the reviewed papers. 4) Outcome: the selected papers are articles that has impact student knowledge and skills, such as learning outcomes, thinking skills, motivation, high-level skills, and various 21st-century skills needed by students.

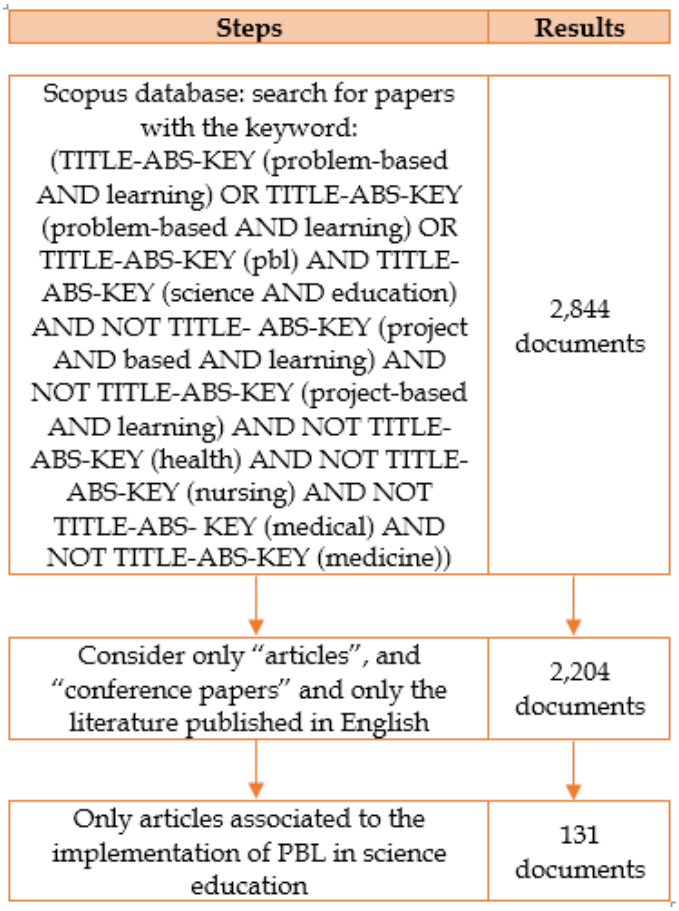

Figure 2. Articles selection procedure and results

Locating studies

Data collection was approved out using the Scopus database. The data is traced using titles related to PBL, namely: "problem-based learning", and "pbl". The focus of data search in the field of science education is then added with the keyword "science education". The data search was carried out over the last 10 years (2013-2022).

Selecting the body of literature

The selection of papers begins with use of predefined keywords. Next choose the type of paper and the use of language. The type of paper selected is only journal publications and proceedings written in English. The final selection stage is selecting papers that are related to the topic of implementing PBL in science education one by one. The series of paper selection is presented in Figure 2.

Bibliometric Analysis Results

Citation Network Analysis (CNA)

The development of research on PBL in science education from time to time is presented in Figure 3. It appears that the amount of publications during the 2013-2022 period fluctuated and tended to increase. The fewest papers produced were in 2014 (n=2), 2016 (n=4), and 2017 (n=7). The growth in the number of publications began in 2014 and the highest increase will be in 2021 with 39 papers. This indicates that PBL has become a hot topic of research to be implemented in science education in recent years.

Based on the analysis, it is known that 117 authors published research results over ten years between 2013 and 2022. A total of 14 authors published two Scopus articles; two authors published three (3) articles; one author published four (4) articles and five (5) articles. In other words, most authors published only one article during this period. If you look at the quantity of article citations each year, it can be understood in Figure 4 that the number of citations fluctuates each year and the highest citations are in 2019. This number is in line with the number of documents published that year. If calculated, on average each published article receives an average of 5.82 citations and each publication averages around 76.20 citations per year.

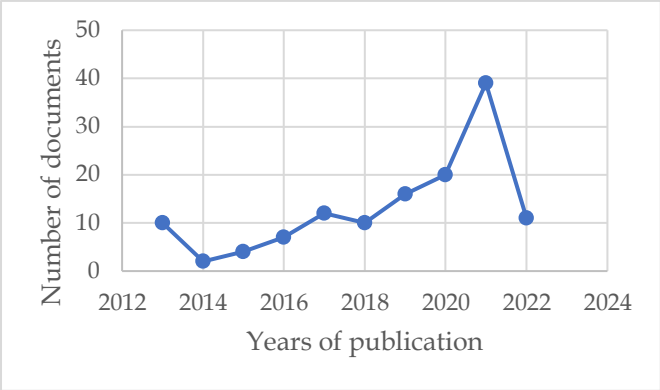

Figure 3. Number of papers relevant to PBL topics in science education in the 2013-2022 period

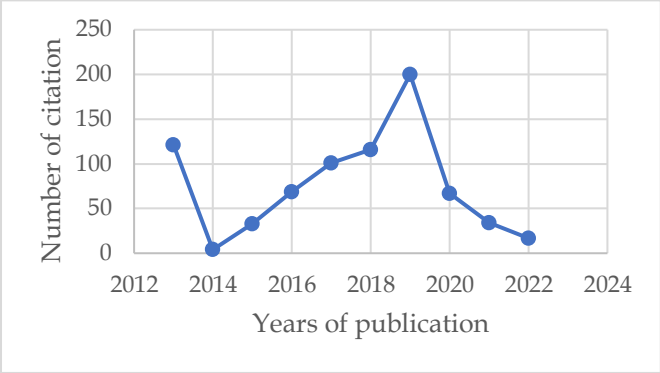

Figure 4. Number of article citations on PBL topics in science education each year in the 2013-2022 period.

Then it is analyzed regarding the most influential researchers using PBL in science education in total citations from 2013 to 2022. The results of the analysis are exposed in Table 1. It can be seen that Fidan M is the most quoted as a whole, namely 124 citations and followed by Kim NJ with 62 citations Allchin D with 45 citations. The article published by Fidan M has been widely cited because PBL is integrated with augmented reality, a hot topic currently being researched in the field of education.

Table 1. The ten most influential writers using PBL in science education in the 2013-2022 period

Cites	Corresponding Authors	Title	Publications year	Source
124	Fidan M.	Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education	2019	Computers and Education
62	Kim NJ	Effectiveness of Computer-Based Scaffolding in the Context of Problem-Based Learning for Stem Education: Bayesian Meta-analysis	2018	Educational Psychology Reviews
45	Allchin D.	Problem- and case-based learning in science: An introduction to distinctions, values, and outcomes	2013	CBE Life Sciences Education
32	Tosun C.	The effect of problem-based learning on undergraduate students' learning about solutions and their physical properties and scientific processing skills	2013	Chemistry Education Research and Practice

Cites	Corresponding Authors	Title	Publications year	Source
28	Panda P.	The validity and effectiveness of physics independent learning model to improve physics problem solving and self-directed learning skills of students in open and distance education systems	2017	Journal of Baltic Science Education
26	Chonkaew P.	Development of analytical thinking abilities and attitudes towards science learning of grade-11 students through science technology engineering and mathematics (STEM education) in the study of stoichiometry	2016	Chemistry Education Research and Practice
25	Belland BR	A Blended Professional Development Program to Help a Teacher Learn to Provide One-to-One Scaffolding	2015	Journal of Science Teacher Education
17	Laredo T.	Changing the first-year chemistry laboratory manual to implement a problem-based approach that improves student engagement	2013	Journal of Chemical Education
15	Parno	A case study on comparison of high school students' scientific literacy competencies domain in physics with different methods: PBL-stem education, PBL, and conventional learning	2020	Journal of Indonesian Science Education
15	Penuel WR	Developing tasks to assess phenomenon-based science learning: Challenges and lessons learned from building proximal transfer tasks	2019	Science Education

To provide an overview of the distribution of countries that influence PBL research in science education, the author's country is examined, followed by the number of publications and citations. The results are presented in Figure 5. The most influential countries in publishing PBL research in science education were Indonesia (n=51), the United States (n=26), and Turkey (n=13). Meanwhile, if seen from the number of citations, the influential countries were the United States (n=274), Turkey (n=216), and Indonesia (n=133).

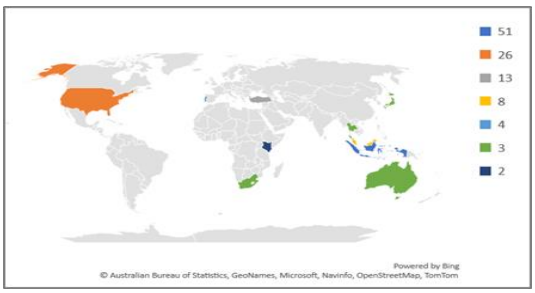

Figure 5a. Country of Authors seen from the number of publications

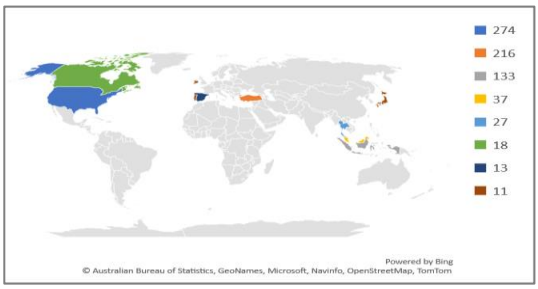

Figure 5b. Author's country seen from the number of citations

Furthermore, an investigation of the relationship between authors was approved out based on the co-author network to see the relationship between corresponding authors. The results are presented in Figure 6. The authors were limited to at least two joint publications in the grouping criteria. Based on Figure 6, the collaboration of researchers on the topic of PBL in science education is still relatively small. This shows that the published articles are not related to other articles. In comparison, collaborative research is essential in promoting scientific productivity, knowledge development, and scientific superiority (Putri et al, 2023) in modern science.

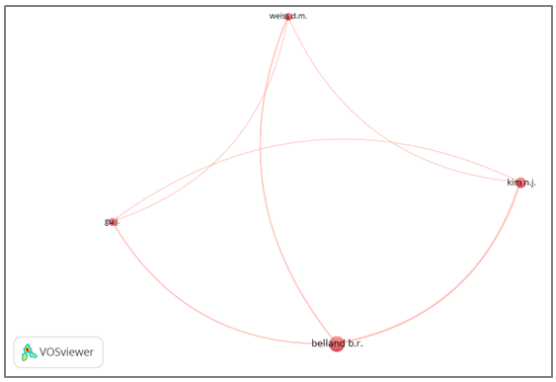

Figure 6. Relationship between researchers (authors) in pbl research in science education

Network Analysis of the Keyword Cooccurrences

To inform the emerging themes of PBL research in science education from time to time, a co-word analysis was conducted. The data used comes from the title of the

article and abstract. Data was collected from all Scopus articles (i.e. 131 papers), analyzed and visualized using VOSviewer software by set the software on its default parameters (i.e. keywords must appear together in at least 5 papers). The results obtained were 171 keywords, but only 35 relevant keywords were used in the analysis. We removed some keywords that have the same meaning and low relevance scores. The analysis results yielded 4 clusters (Table 2) which were ordered by the occurrence of the keywords together (i.e., the frequency of occurrence of the keywords in the data set). The keyword network visualization is presented in Figure 7.

In Figure 7, the size of font represents the relative frequency of occurrence of keywords and the linking lines signify the co-occurrence of keywords. Repeating term sets are highlighted with the same color. It appears that the green cluster is the largest cluster with the highest frequency of occurrence of keywords consisting of 10 keywords (Table 2). The Red cluster is the second largest cluster which consists of 11 keywords. Then followed by the third and fourth clusters, namely the green and blue clusters. Based on co-word analysis for PBL research in science education, it was concluded that there are several keywords that rarely appear, for example physics, scientific literacy, 21st century skills, chemistry education, biology, inquiry, computer, and senior high school. Furthermore, to see the development of keyword emergence by year, co-words are visualized in Figure 8.

Table 2. Distribution of keywords for each cluster

Cluster	Color	Number of Items	Keywords
Cluster 1	Red	11	21st century learning, ability, case study, high school student, learning model, PBL model, physics, science learning, scientific literacy, senior high school, student's problem
Cluster 2	Green	10	Biology, case, computer, knowledge, PBL approach, science, science education, teacher, undergraduate student, understanding
Cluster 3	Blue	10	Assessment, challenge, chemistry education, critical thinking skill, e-module, environment, higher order thinking skill, module, natural science, student critical thinking
Cluster 4	Yellow	4	Inquiry, STEM, technology, tools

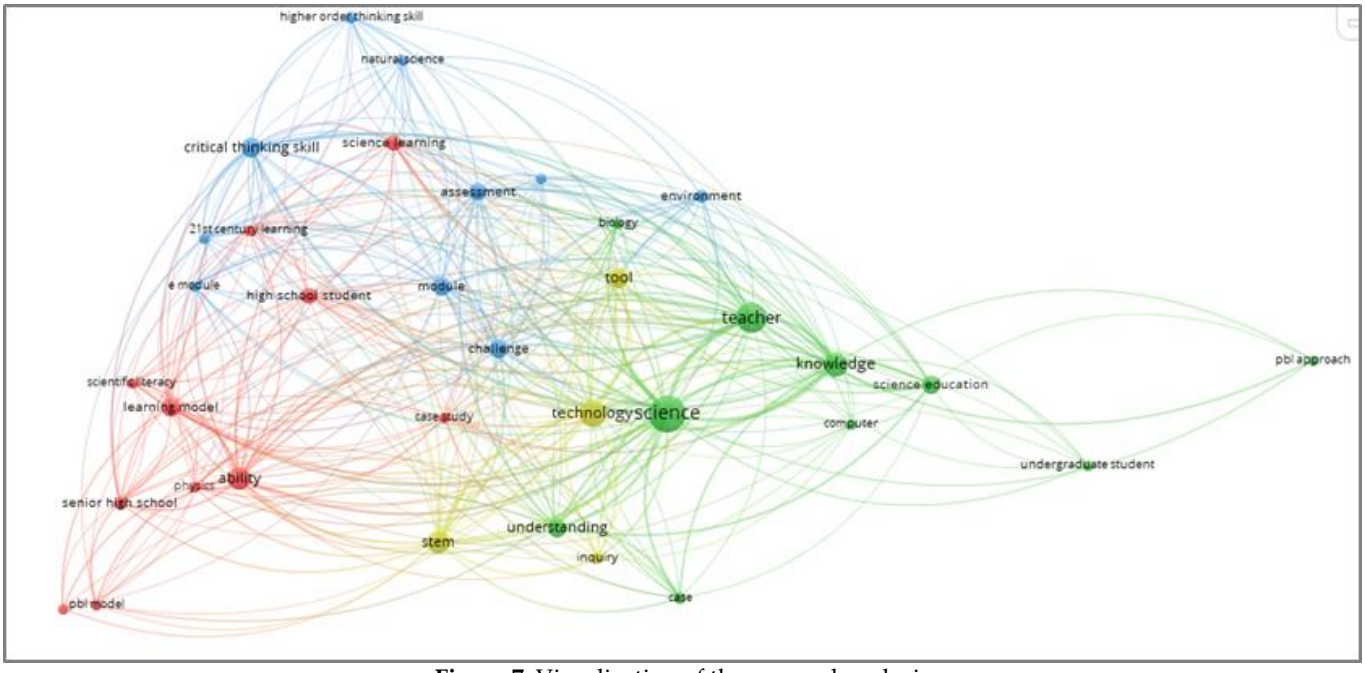

Figure 7. Visualization of the co-word analysis

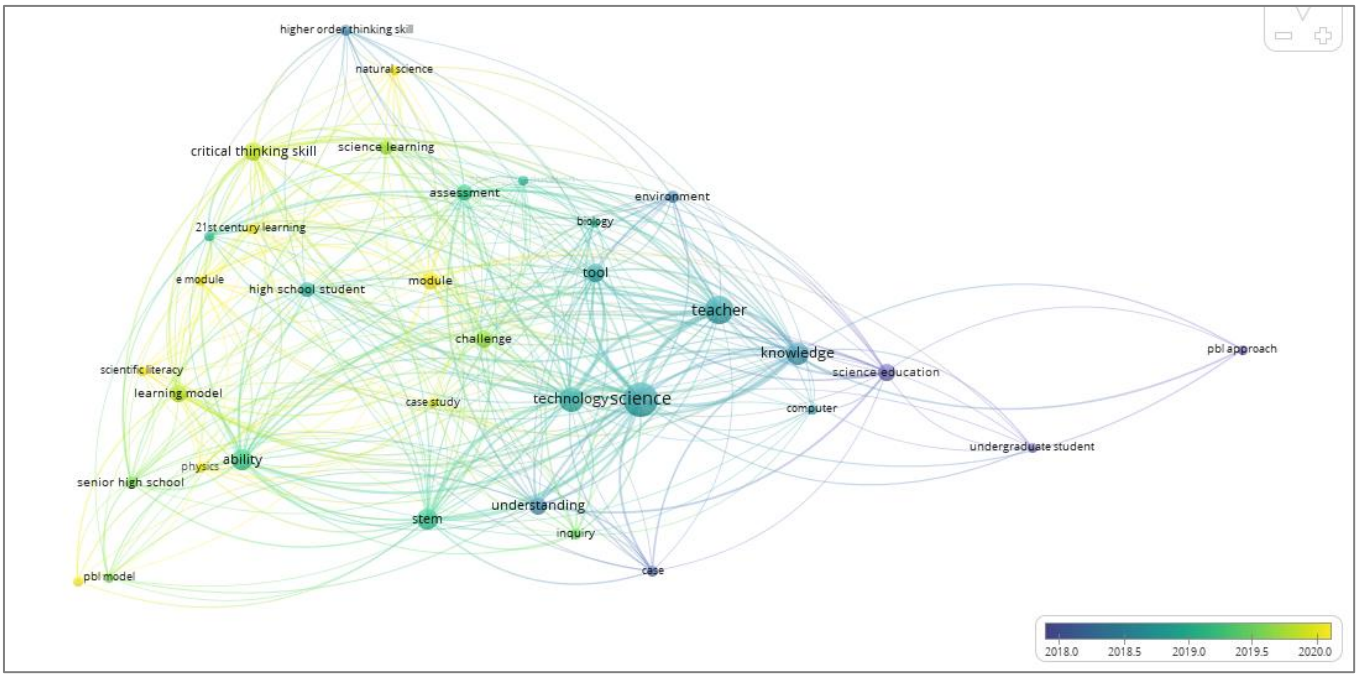

Figure 8. Visualization of The Overlay of the co-word analysis results

The rapid development of technology has also influenced the growth of 21st-century learning, especially in learning physics. These developments have made physics learning carried out with the help of digital technology, such as digital modules. Figure 8 shows that PBL research is also related to the topic of electronic learning modules (Purnamasari & Utomo, 2020; Seruni et al., 2020; Kurniati et al., 2021; Yunita et al., 2021), which is the latest topic being researched (topics marked in yellow clusters). Other recent PBL research topics are related to other topics, namely 21st-century learning (Marshel & Fauzi, 2021; Ranggi et al., 2021; Parno et al., 2020; Saputro et al., 2020), physics (Wibowo, 2021; Parno et al., 2020), critical thinking (Marthaliakirana et al., 2022; Susanto et al., 2022; Rehmat & Hartley, 2020; Seruni et al., 2020; Saputro et al., 2020; Puspita & Aloysius, 2019; Hakim & Meidawati, 2019; Rubini et al., 2019), and scientific literacy (Amaringga et al., 2021; Parno et al., 2020; Wibowo, 2021).

Discussion

This research is the first study to conduct SLNA on PBL research in science education during the last ten years, from 2013-2022. In education, using the PBL model is a hot topic for discussion. The analysis results show that the quantity of published articles on PBL in science education fluctuates but tends to increase. Publications have increased since 2014 and the most in 2021, totaling 39 articles. Research on PBL is currently gaining popularity because the PBL model is in accordance with 21st-century learning. Learning with the PBL model can facilitate students in generating creative ideas and encourage students to discuss and debate specific issues that are being discussed (Ismail et al., 2018). This spontaneously encourages and increases students' HOTS. PBL views learning as the result of working toward understanding and solving problems to allow students to progress critical thinking skills in relation to the ideas they receive and decide what action to take based on the information they receive (Anggraeni et al., 2023; Amin et al., 2020). The PBL model facilitates students in connecting the concepts learned with real world problems (Heong et al., 2020). This reveals that the PBL model facilitates students in developing 21st-century skills, such as critical (Marthaliakirana et al., 2022; Susanto et al., 2022; Rehmat & Hartley, 2020; Seruni et al., 2020; Saputro et al., 2020; Puspita & Aloysius, 2019; Hakim & Meidawati, 2019; Rubini et al., 2019) and creative thinking skills (Wahyudiati, 2022; Sumarni & Sekarini, 2020).

The most influential authors using PBL in science education can be seen from the amount of citations in the last ten years: Fidan M with a Turkish state affiliation, Kim NJ, and Allchin D with United States state affiliation. This is also in line with the finding that the USA is the top country and the most influential country based on the quantity of citations. However, based on the number of publications about PBL in science education, the country that publishes the most in Indonesia, while the USA is in second place and Turkey is in third place. These findings indicate that PBL research in science education has been carried out by various countries and not only in the United States but has even become a research topic for researchers in

Indonesia. The increasing trend of PBL research in Indonesia is inseparable from existing curriculum policies in Indonesia, both at the secondary and tertiary education levels. Indonesia has implemented a science education curriculum that emphasizes the use of the PBL model in secondary education since the emergence of the 2013 curriculum.

The results of the co-word analysis show that the most relevant keywords in PBL research in science education include science, technology, teacher, knowledge, critical thinking, and others. These findings indicate that research trends on PBL are often associated with the use of technology, teacher abilities, and students' critical thinking skills. Meanwhile, topics related to 21st century skills, the application of PBL to high school students and the competency development of prospective teachers are still very limited. The results shown in Figure 5 show that PBL is rarely studied in physics education. This indicates that the application of PBL is still dominated by science education in general, thereby opening up opportunities for PBL research innovations that are oriented towards 21st century skills in physics content.

The finding that the application of PBL to secondary school students is rarely carried out is in line with a meta-analytic study conducted by Moallem et al. (2019). The results show that the application of PBL in education is more dominated at the tertiary level than at the secondary school level. Teachers show interest in PBL but teachers feel burdened and find it difficult to implement PBL in the classroom.

Figure 6 also shows the latest trends in PBL research related to keywords such as module/e-module, scientific literacy, natural science, and physics. While keywords such as science education, environment, and undergraduate student are keywords that have been researched for a long time. This indicates an opportunity to carry out the latest research on the application of PBL for undergraduate students. Universities need to include training in the curriculum to upsurge the understanding and skills of pre-service teachers in designing and implementing 21st century skill-oriented learning through the PBL model. This was also revealed by (Hakkinen et al., 2017), that the education of prospective teachers can be a powerful resource for triggering long-term alteration and supporting the incorporation of 21st century skills in daily school practice.

Conclusion

PBL has developed one of the areas of study that has experienced significant growth and improvement and its contribution to the world of education, especially in science education. The findings can be concluded that the number of PBL publications in science education tends to increase from year to year and the most publications are in 2019. Indonesia is the top country in publishing PBL research in science education, and the United States is the top country in publications based on the number of citations. The most influential authors based on the number of citations for PBL research in science education are Fidan M with Turkish state affiliation, Kim NJ and Allchin D with United States state affiliation. Collaboration between authors is still rare and there are only four authors who collaborate with each other with two number of joint publications. The top keywords in PBL research in science education, ordered by link strength, are science (192), teacher (149), and technology (126). This research is limited to the Scopus database. Through the results of the mapping and visualization shapes of the implications of this research, we tend to discover the novelty of research on PBL research, and trends in science education over the past ten years (2013-2022). Future researchers are expected to extend the metadata by adding other metadata, such as Google Scholar and Web of Science, and combining them. Researchers can also narrow down the following trends that can be developed in this research field, for example the application of PBL in learning Physics or the field of Physics education. In addition, future researchers can explore PBL in science teacher education and 4C skill-oriented learning. Finally, this publication can become the basis for future research, so that it has great citation and impact on the implementation of PBL in science education.

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Author Contributions

Nurhayati was in charge of conceptualization, design of methodology, data curation, software processing and visualization of data, investigation, and manuscript writing – original draft and finishing. Andi Suhandi was in charge of validation, data resources, supervision, manuscript writing—review and editing. Muslim and Ida Kaniawati were in charge of validating and supervising the project for this publication. All authors discussed the results and contributed to the final manuscript.

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Conflicts of Interest

The authors declare no conflicts of interest in this study. The sponsor also played no role in the design of the study, in collecting, analyzing or interpreting data; when writing manuscripts; or when we decide to publish the results.

References

Abdullah, K.H. (2022). Publication trends in biology education: a bibliometric review of 63 years. *Journal of Turkish Science Education*, *19*(2), 465–480. https://doi.org/10.36681/tused.2022.131

Amaringga, N. G., Amin, M., & Irawati, M. H. (2021). The effect of problem-based learning module containing research result to improve students' scientific literacy. *In AIP Conference Proceedings*, 2330(1). https://doi.org/10.1063/5.0043529

Amin, S., Utaya, S., Bachri, S., & Susilo, S. (2020). Effect of problem-based learning on critical thinking skills and environmental attitude. *Journal for the Education of Gifted Young Scientists*, *8*(2), 743–755. https://doi.org/10.17478/jegys.650344

Anggraeni, D. M., Prahani, B., Suprapto, N., Shofiyah, N., & Jatmiko, B. (2023). Systematic review of problem based learning research in fostering critical thinking skills. *Thinking Skills and Creativity*, *49*, 1-12. https://doi.org/10.1016/j.tsc.2023.101334

Barrows, H. S. (1984). A specific problem-based, self-directed learning method designed to teach medical problem-solving skills, and enhance knowledge retention and recall. *Tutorials in Problem-Based Learning*, 16–32. Retrieved from https://pubmed.ncbi.nlm.nih.gov/6644989/

Colicchia, C., Creazza, A., Noè, C., & Strozzi, F. (2019). Information sharing in supply chains: a review of risks and opportunities using the systematic literature network analysis (SLNA). *Supply Chain Management: An International Journal* , *24*(1), 5–21. https://doi.org/10.1108/SCM-01-2018-0003

Effendi, DN, Irwandani, Anggraini, W., Jatmiko, A., Rahmayanti, H., Ichsan, IZ, & Rahman, MM (2021). Bibliometric analysis of scientific literacy using vos viewer: analysis of science education. *Journal of Physics: Conference Series*, *1796*(1). https://doi.org/10.1088/1742-6596/1796/1/012096

Fadillah, L., Kartono, K., & Supriyadi, S. (2019, February). Peran Tutor Feedback dalam Model PBL pada Pencapaian Kemampuan Komunikasi Matematis ditinjau dari Gaya Kognitif. In *PRISMA, Prosiding Seminar Nasional Matematika, 2*, 533-539. Retrieved from https://journal.unnes.ac.id/sju/index.php/prisma/article/view/29047

Fidan, M., & Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers and Education*, *142*, 1-19. https://doi.org/10.1016/j.compedu.2019.103635

Goli, F., & Haghighinasab, M. (2022). Dynmic pricing: A bibliometric approach. *Iranian Journal of Management Studies*, *15*(1), 111–132. https://doi.org/10.22059/ijms.2021.315212.674336

Hakim, M. I., & Meidawati, R. (2019). The implementation of problem based learning model with the science writing heuristic approach to increase mastery of concept and critical thinking skill at junior high school student on simple machine. *In Journal of Physics: Conference Series*, *1280*(5), 1-6. https://doi.org/10.1088/1742-6596/1280/5/052074

Hakkinen, P., Jarvela, S., Makitalo-Siegl, K., Ahonen, A., Naykki, P., & Valtonen, T. (2017). Preparing teachers–students for twenty-first-century learning practices (PREP 21): A framework for enhancing collaborative problem-solving and strategic learning skills. *Teachers and Teaching*, *23*(1), 25–41. https://doi.org/10.1080/13540602.2016.1203772

Hallinger, P. (2021). Tracking the Evolution of the Knowledge Base on Problem-based Learning: A Bibliometric Review, 1972-2019. *Interdisciplinary Journal of Problem-Based Learning*, *15*(1). https://doi.org/10.14434/ijpbl.v15i1.28984

Heong, Y. M., Hamdan, N., Ching, K. B., Kiong, T. T., & Azid, N. (2020). Development of integrated creative and critical thinking module in problem-based learning to solve problems. *International Journal of Scientific and Technology Research, 9*(3), 6567–6571. Retrieved from https://www.ijstr.org/final-print/mar2020/Development-Of-Integrated-Creative-And-Critical-Thinking-Module-In-Problem-based-Learning-To-Solve-Problems.pdf

Ismail, NS, Harun, J., Zakaria, MAZM, & Salleh, SM (2018). The effect of mobile problem-based learning application dicscience pbl on students' critical thinking. *Thinking Skills and Creativity*, *28*, 177–195. https://doi.org/10.1016/j.tsc.2018.04.002

Jdaitawi, M. (2020). The effect of using problem based learning upon students' emotions towards learning and levels of communication skills in three different disciplines. *Croatian Journal of Education*, *22*(1), 207–240. https://doi.org/10.15516/cje.v22i1.3215

Khitous, F., Strozzi, F., Urbinati, A., & Alberti, F. (2020). A systematic literature network analysis of existing themes and emerging research trends in circular economy. *Sustainability (Switzerland)*, *12*(4), 1-24.

https://doi.org/10.3390/su12041633

Khoiriyah, A.J., & Husamah, H. (2018). Problem-based learning: creative thinking skills, problem-solving skills, and learning outcomes of seventh grade students. *JPBI (Journal of Indonesian Biology Education)*, *4*(2), 151–160. https://doi.org/10.22219/jpbi.v4i2.5804

Kurniati, R. D., Andra, D., & Distrik, I. W. (2021). E-module development based on PBL integrated STEM assisted by social media to improve critical thinking skill: a preliminary study. *In Journal of Physics: Conference Series*, *1796*(1), 1-9. https://doi.org/10.1088/1742-6596/1796/1/012077

Kuvac, M., & Koc, I. (2018). The effect of problem-based learning on the metacognitive awareness of pre-service science teachers. *Educational Studies*, *45*(5), 646–666. https://doi.org/10.1080/03055698.2018.1509783

Marshel, J., & Fauzi, A. (2021). Practicality of student worksheets science based on problem based learning models with the theme of the motion in life using integrated connected type 21st century learning. *In Journal of Physics: Conference Series*, *1876*(1), 1-8. https://doi.org/10.1088/1742-6596/1876/1/012050

Marthaliakirana, A. D., Suwono, H., Saefi, M., & Gofur, A. (2022). Problem-based learning with metacognitive prompts for enhancing argumentation and critical thinking of secondary school students. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(9), 1-15. https://doi.org/10.29333/ejmste/12304

Miner-Romanoff, K., Rae, A., & Zakrzewski, CE (2019). A holistic and multifaceted model for ill-structured experiential problem-based learning: Enhancing student critical thinking and communication skills. *Journal of Problem Based Learning in Higher Education*, *7*(1), 70-96. https://doi.org/10.5278/ojs.jpblhe.v7i1.3341

Moallem, M., Hung, W., & Dabbagh, N. (2019). *The Wiley handbook of problem-based learning*. John Wiley & Sons.

Newman, M., & Gough, D. (2020). Systematic reviews in educational research: Methodology, perspectives and application. In *Systematic Reviews in Educational Research,* 3–22. https://doi.org/10.1007/978-3-658-27602-7_1

Nurdin, BV, Hutagalung, SS, Yulianto, Kurniawan, RC, & Hermawan, D. (2021). Bibliometric Analysis on Governance Index Topics Using Scopus Database and Vosviewer. *Journal of Physics: Conference Series*, *1933*(1). https://doi.org/10.1088/1742-6596/1933/1/012047

Parno, P., Yuliati, L., Hermanto, F. M., & Ali, M. (2020). A case study on comparison of high school students' scientific literacy competencies domain in physics with different methods: pbl-stem education, pbl, and conventional learning. *Jurnal Pendidikan IPA Indonesia*, *9*(2), 159-168. https://doi.org/10.15294/jpii.v9i2.23894

PhamDuc, B., Tran, T., Le, HTT, Nguyen, NT, Cao, HT, & Nguyen, TT (2021). Research on Industry 4.0 and on key related technologies in Vietnam: A bibliometric analysis using Scopus. *Learned Publishing*, *34*(3), 414–428. https://doi.org/10.1002/leap.1381

Purnamasari, D., & Utomo, S. B. (2020). Analysis of STEM-PBL based e-module needs to improve students' critical-thinking skills. *In Journal of Physics: Conference Series*, *1511*(1), 1-7. https://doi.org/10.1088/1742-6596/1511/1/012096

Puspita, A. S., & Aloysius, S. (2019). Developing student's critical thinking skills through implementation of problem based learning approach. *In Journal of Physics: Conference Series*, *1241*(1), 1-8. https://doi.org/10.1088/1742-6596/1241/1/012020

Putri, A. H., Samsudin, A., Purwanto, M. G., & Suhandi, A. (2022). Examination of conceptual change research over a decade: a bibliometric analysis using science mapping tool. *Indonesian Journal on Learning and Advanced Education (IJOLAE),* 4(3), 171-190. https://doi.org/10.23917/ijolae.v4i3.18249

Ranggi, N. L., Ramli, M., & Yuliani, H. (2021). Meta-analysis of the effectiveness of problem-based learning towards critical thinking skills in science learning. *In Journal of Physics: Conference Series*, *1842*(1), 1-9. https://doi.org/10.1088/1742-6596/1842/1/012071

Rehmat, A. P., & Hartley, K. (2020). Building engineering awareness: Problem based learning approach for STEM integration. *Interdisciplinary Journal of Problem-Based Learning*, *14*(1), 1-15. https://doi.org/10.14434/ijpbl.v14i1.28636

Rubini, B., Septian, B., & Permana, I. (2019). Enhancing critical thinking through the science learning on using interactive problem based module. In *Journal of Physics: Conference Series*, *1157*(2), 1-5. https://doi.org/10.1088/1742-6596/1157/2/022001

Saputro, A. D., Atun, S., Wilujeng, I., Ariyanto, A., & Arifin, S. (2020). Enhancing pre-service elementary teachers' self-efficacy and critical thinking using problem-based learning. *European Journal of Educational Research*, *9*(5), 765-773. https://doi.org/10.12973/eu-jer.9.2.765

Sebatana, M. J., & Dudu, W. T. (2022). Enhancing grade 10 physical sciences teachers' self-directedness in implementing blended problem-based learning. *Science Education International*, *33*(4), 427-437. https://doi.org/10.33828/sei.v33.i4.11

Seruni, R., Munawaroh, S., Kurniadewi, F., & Nurjayadi, M. (2020, March). Implementation of e-module flip PDF professional to improve students' critical thinking skills through problem based learning. *In Journal of Physics: Conference Series*, *1521*(4), 1-5. https://doi.org/10.1088/1742-6596/1521/4/042085

Shishigu, A., Hailu, A., & Anibo, Z. (2018). Problem-based learning and conceptual understanding of college female students in physics. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(1), 145–154. https://doi.org/10.12973/ejmste/78035

Simanjuntak, M.P., Hutahaean, J., Marpaung, N., & Ramadhani, D. (2021). Effectiveness of problem-based learning combined with computer simulation on students' problem-solving and creative thinking skills. *International Journal of Instruction*, *14*(3), 519–534. https://doi.org/10.29333/iji.2021.14330a

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

Sumarni, W., & Sekarini, A. P. (2020). Review of learning strategies to improve creative thinking skills. *In Journal of Physics: Conference Series*, *1567*(4), 1-5. https://doi.org/10.1088/1742-6596/1567/4/042050

Supriadi, U., Supriyadi, T., Abdussalam, A., & Rahman, AA (2020). A decade of value education model: a bibliometric study of scopus database in 2011-2020. *European Journal of Educational Research*, *9*(3), 921–934. https://doi.org/10.12973/eu-jer.11.1.557

Susanto, T. T. D., Dwiyanti, P. B., Marini, A., Sagita, J., Safitri, D., & Soraya, E. (2022). E-book with problem based learning to improve student critical thinking in science learning at elementary school. *International Journal of Interactive Mobile Technologies*, *16*(20), 4-17. https://doi.org/10.3991/ijim.v16i20.32951

Thu, H.L.T., Tran, T., Phuong, TTT, Tuyet, TLT, Huy, H. Le, & Thi, TV (2021). Two decades of stem education research in middle school: A bibliometrics analysis in Scopus database (2000–2020). *Education Sciences*, *11*(7). https://doi.org/10.3390/educsci11070353

Wahyudi, W., Setiawan, A., & Suhandi, A. (2023). Trend and opportunity of science education research related optical waves: a systematic literature network analysis. *JIPF (Jurnal Ilmu Pendidikan Fisika)*, *8*(2), 168-182. https://dx.doi.org/10.26737/jipf.v8i2.3685

Wahyudiati, D. (2022). The critical thinking skills and scientific attitudes of pre-service chemistry teachers through the implementation of problem-based learning model. *Jurnal Penelitian Pendidikan IPA*, *8*(1), 216-221. https://doi.org/10.29303/jppipa.v8i1.1278

Wartono, W., Diantoro, M., & Bartlolona, JR (2018). Influence of problem based learning model on student creative thinking on elasticity topics a material. *Indonesian Journal of Physics Education* , *14*(1), 32–39. https://doi.org/10.15294/jpfi.v14i1.10654

Wibowo, F. C. (2021). Unveil problem based learning on physics learning: a literature review. *In Journal of Physics: Conference Series*, *2019*(1), 1-6. https://doi.org/10.1088/1742-6596/2019/1/012045

Williams, B. (2020). Dimensions & VOSViewer Bibliometrics in the Reference Interview. *Code4LibJournal*, *47*. Retrieved from https://journal.code4lib.org/articles/14964

Yaman, S., & Yalçın, N. (2020). Effectiveness on creative thinking skills of problem based learning approach in science teaching. *Elementary Education Online* , *4*(1), 42–42. Retrieved from https://www.ilkogretim-online.org/?mno=121162

Yunita, A., Suyidno, S., & Syahmani, S. (2021). The validity of science e-module based on the authentic problem. *In Journal of Physics: Conference Series*, *1760*(1), 1-5. https://doi.org/10.1088/1742-6596/1760/1/012037