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A Bibliometric Study on the Impact of Teaching Material Utilization in Quantum Physics Instruction Using the Problem-Based Learning Models

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ABSTRACT

Quantum physics presents significant conceptual challenges due to its abstract nature and incompatibility with students' everyday logic, often resulting in misconceptions and low conceptual understanding. Teaching materials that are not contextually grounded and conventional instructional models further exacerbate the difficulty of quantum physics learning. Considering the importance of mastering quantum concepts in higher education, particularly in preparing future physics educators, innovative teaching approaches are urgently needed. This study aims to investigate research trends on the use of contextual teaching materials in quantum physics instruction employing Problem-Based Learning (PBL) models through bibliometric analysis. By analyzing 100 articles from 2015 to 2025 using Publish or Perish and VOSviewer, this study identifies dominant research focuses, including the role of analogies, PBL modules, and immersive technologies in enhancing conceptual understanding. The results are expected to inform future developments in quantum physics education by highlighting effective pedagogical strategies supported by teaching materials and student-centered learning models.

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INTRODUCTION

Measurement physics is a fundamental branch of physics that provides a conceptual basis for understanding microscopic phenomena, such as atomic structure, the working principles of semiconductors, and modern measurement technology (Auffèves, 2022). This material has strategic value in the development of technology and scientific innovation, so it is a compulsory course in the physics education curriculum at various universities (Capriconia & Mufit, 2022; Pandiangan, 2023). However, the complexity of concepts in physics often makes it difficult for students, especially due to limited empirical experience of phenomena that cannot be observed directly (Anshu & Arunachalam, 2023). The non-deterministic character of coupling theory also conflicts with everyday logical thinking patterns, causing cognitive conflict and context confusion in the learning process (Krijtenburg-Lewerissa et al., 2019; Mufit et al., 2023, 2024)

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In learning quantum physics, teaching materials play an important role as a bridge between abstract theoretical concepts and more concrete and easily understood understanding by students. When teaching materials are designed contextually, students can more easily understand quantum concepts that are intuitively difficult to understand (Aehle et al., 2022). Providing context through real-world situations or technological applications, such as the photoelectric effect, superposition in quantum computers, or the working principle of lasers, allows students to construct meanings that are closer to their everyday experiences. Contextual teaching materials support the integration of various learning elements such as visual representations, analogies, and interactive simulations, all of which are very helpful in simplifying complex quantum ideas (Aehle et al., 2022; Stoy et al., 2021; Zamprogno Rebello et al., 2020). Visualizations such as wave functions or probability diagrams, for example, can strengthen students' conceptual understanding without relying entirely on complicated mathematical formulations (Man'ko & Man'ko, 2021; Passante & Kohnle, 2019).

Learning models also play an important role in creating effective learning experiences. Problem-Based Learning (PBL) is an innovative pedagogical approach that places students at the center of learning through solving authentic and complex problems (Saputri & Wisudawati, 2025). This model encourages students to be actively involved in exploring, evaluating and synthesizing relevant information to understand the concepts being learned (Şahin & Kılıç, 2024). The application of PBL in quantum physics learning has been proven to improve students' critical thinking skills and conceptual understanding, which are very much needed in dealing with abstract and challenging material.

Given the inherent challenges in teaching quantum physics and the significant potential of teaching materials and the Problem-Based Learning (PBL) model, this study adopts a bibliometric approach to analyze relevant scientific literature. The bibliometric method enables a systematic identification of patterns, trends, and developments in research related to the impact of teaching material utilization and the implementation of problem-based learning models in quantum physics instruction. By analyzing publication data such as citation counts, authors, titles, and publication years of the most influential articles, this study aims to provide a comprehensive overview of the research landscape in this field. This approach will help identify prominent research focuses, such as the role of analogies and PBL modules in enhancing critical thinking, as well as the potential of immersive technologies in quantum physics learning. Thus, it is expected to highlight areas that require further exploration to improve the effectiveness of quantum physics education.

METHODS

This writing uses the bibliometric analysis method. Bibliometric analysis is an approach used to identify systematic patterns in various types of literature related to a particular theme (Rahmawati et al., 2022). This method plays an important role in evaluating the results of scientific research and mapping scientific fields, including tracking the development of new knowledge in a particular area (Effendy et al., 2021). In addition, bibliometric analysis presents a spatial representation of the relationship between scientific fields, topics, publications, and authors (Fajri et al., 2024; Moreno-Guerrero et al., 2020)

This bibliometric analysis method has general research stages, namely determining topic criteria, identifying relevant studies (identification process), developing a search strategy, conducting searches and filtering to find important points from selected sources, and describing, analyzing, and synthesizing research results (Mainey et al., 2020; Meiyanti et al., 2019; Papakonstantinou et al., 2020; Safitri & Admoko, 2024). To produce relevant discussions and conclusions, the VOSviewer analysis tool is used as a data processing application.

The data collection process in this study used the Publish or Perish (PoP) application and VOSviewer as a data analysis application. The steps of the research procedure can be seen in Figure 1

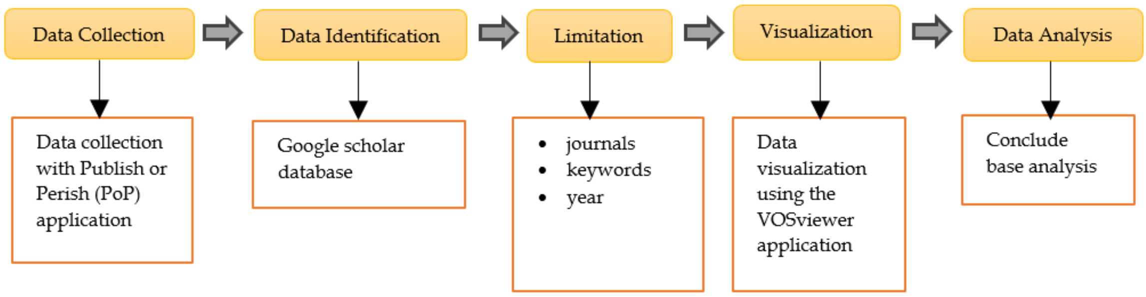

Figure 1 Research Procedures

Data collection was carried out using the Publish or Perish (PoP) application through several stages, namely: (1) selecting Google Scholar as the article search database, (2) entering the keywords "teaching materials, quantum physics, problem-based learning", and (3) obtaining search results in the form of articles in the 2015–2025 time frame. After the data is obtained, the next step is to carry out bibliometric mapping and analysis using the VOSviewer application. In determining the articles to be used, inclusion and exclusion criteria are required. which can be seen in Table 1.

Table 1 Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Relevant topics: Articles must discuss the use of teaching materials in teaching quantum physics and/or problem-based learning models	Irrelevant topics : Articles that do not discuss either the use of teaching materials, quantum physics teaching, or problem-based learning models significantly
Publication types: articles, books, proceedings	Non-scientific publication types: Types of publications that are not journal articles, proceedings, or literature reviews
Language: Indonesian and English	Non-inclusive language: Articles written in languages other than Indonesian or English
Time frame: 2015-2025	Different learning models: Articles that discuss other learning models without any elements of problem-based learning
Focus on education	

All articles that have been collected and are in accordance with the research criteria are then exported for further processing using the VOSviewer software. This software is able to display and interpret bibliographic information maps through visualization and analysis features (Fajri et al., 2024). The results of the analysis in this study are used to identify thematic evolution and current research trends related to digital learning media in science education (Moreno-Guerrero et al., 2020; Wilsa et al., 2023). VOSviewer produces three types of visualizations, namely: (1) Network visualization, (2) Overlay visualization, and (3) Density visualization.

RESULTS AND DISCUSSION

Bibliometric analysis of the impact of using teaching materials on quantum physics courses using the problem-based learning model was conducted using the Publish or Perish (PoP) application for the 2015–2025 period, with Google Scholar as the data source. A total of 100 articles were successfully retrieved. Data collected through the PoP application were stored in RIS format and then analyzed using Microsoft Excel and VOSviewer.

The collected data was initially analyzed by organizing it in Microsoft Excel. The analysis of the development trends revealed the number of relevant publications on the topic within the 2015–2025 period, as illustrated in Figure 2.

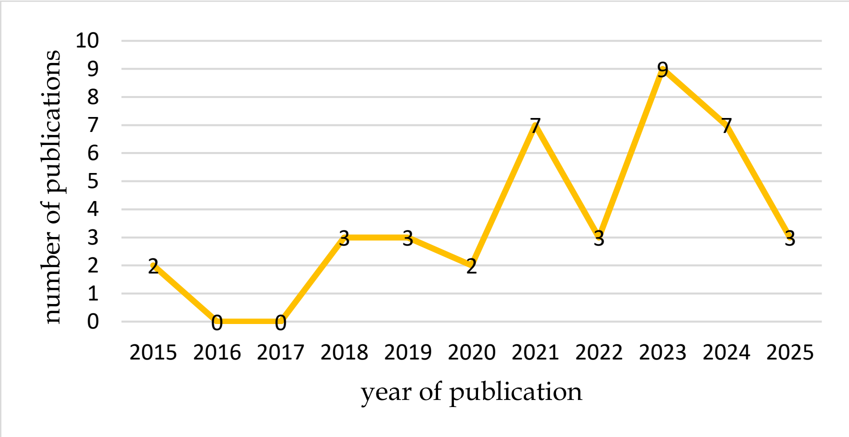

Figure 2 Number of Publications in 2015-2025

Figure 2 shows the results of article publications in the period 2015-2025. The graphical image shows the trend of publications related to quantum physics learning during the period 2015–2025, reflecting the dynamics of academic attention to this topic. The number of publications fluctuated, with a stagnant phase in 2016 and 2017 (no publications), then began to increase in 2018 to peak in 2023 with 9 publications. A significant spike occurred in 2021 and 2023, which may have been influenced by increased attention to curriculum development and learning innovation after the pandemic. The decrease in the number of publications after 2023 indicates the possibility of temporary saturation or a shift in research focus. However, the consistency of the number of publications in the range of 2–9 articles per year indicates that this topic remains relevant in the physics education community. This pattern indicates the importance of research continuity and the need for strategies that encourage cross-institutional collaboration so that the development of quantum physics education remains progressive and contextual.

A more detailed analysis was carried out to identify the most cited articles during the 2015–2025 period. This analysis included data on the number of citations, authors, article titles, and publication years. The top 10 most cited articles are presented in Table 2.

Table 2. Top 10 Citations in the 2015-2025 Period

Cites	Authors	Title	Year
202	(Rodrigues et al., 2025)	Role of analogies with classical physics in introductory quantum physics teaching	2025
109	(Saputri & Wisudawati, 2025)	Validity of Problem-Based Learning Teaching Module to Improve Critical Thinking of	2025

		High School Students on Atomic Structure Material	
95	(McAfee et al., 2025)	A review of research on the teaching and learning of quantum mechanics	2025
90	(Şahin & Kılıç, 2024)	Comparison of the effectiveness of project-based 6E learning and problem-based quantum learning: Solomon four-group design	2024
59	(Mufit et al., 2024)	Design Immersive Virtual Reality (IVR) with Cognitive Conflict to Support Practical Learning of Quantum Physics.	2024
48	(Irvani et al., 2024)	Analysis of Quantum Physics Lectures from the Perspective of the MBKM and OBE Based Higher Education Curriculum	2024
30	(Majidy, 2024)	Addressing misconceptions in university physics: A review and experiences from quantum physics educators	2024
26	(Nikolaus et al., 2024)	Investigating Students' Conceptual Knowledge of Quantum Physics to Improve the Teaching and Learning Process	2024
21	(Obbo et al., 2024)	A 5E-based learning experience to introduce concepts relevant in Quantum Physics	2024
19	(Azizah et al., 2024)	The Influence of Quantum Teaching on Problem-solving skills in the Context of Lifelong Learning	2024

The article with the highest number of citations, namely 202 citations, is entitled "Role of analogies with classical physics in introductory quantum physics teaching" by Rodrigues et al. (2025). This high number of citations indicates that the use of analogies from classical physics is crucial in helping students understand abstract quantum physics concepts. This is in line with the argument in the introduction of this study which states that contextually designed teaching materials can bridge the gap between abstract theory and more concrete understanding. Providing context through real situations or technological applications, such as the photoelectric effect, superposition in quantum computers, or the working principle of lasers, allows students to construct meanings that are closer to their everyday experiences.

Problem-based learning (PBL) models are also a major focus, as shown by the article by Saputri & Wisudawati (2025) entitled "Validity of Problem-Based Learning Teaching Module to Improve Critical Thinking of High School Students on Atomic Structure Material," which ranks second with 109 citations. This article emphasizes the relevance of PBL in developing critical thinking skills in students. The PBL model requires active involvement of students in searching, evaluating, and synthesizing relevant information to understand the concepts being studied. Although this study focuses on atomic structure material, the implications are very broad for teaching quantum physics, where critical thinking skills and deep conceptual understanding are essential

In addition, an overview of the research on teaching and learning mechanics compiled by McAfee, Watts, & Rodriguez (2025) with 95 citations, provides a strong theoretical foundation for researchers in this field. This is followed by the research of Şahin & Kılıç (2024) which compared the effectiveness of the 6E project-based learning model with problem-based learning, indicating that there is a continuous effort to teach and optimize teaching strategies.

Technological innovation is also an interesting topic, as shown by the research of F. Mufit, Y. Hendriyani, & M. Dhanil (2024) on "Design Immersive Virtual Reality (IVR) with Cognitive Conflict to Support Practical Learning of Quantum Physics" with 59 citations. This article highlights the potential of immersive technologies such as Virtual Reality (VR) in helping students overcome the complexity of quantum physics concepts and facilitating practical learning. This is very relevant to the statement that contextual teaching materials can support the integration of various learning elements such as visual representations, analogies, and interactive simulations that are very helpful in simplifying complex quantum ideas.

The curriculum aspect is also an important concern, as analyzed by Irvani et al. (2024) in "Analysis of Quantum Physics Lectures from the Perspective of the MBKM and OBE Based Higher Education Curriculum" (48 citations). This reflects an effort to align quantum physics teaching with modern higher education curriculum frameworks such as Independent Learning Independent Campus (ILIC) and OBE (Outcome-Based Education), which emphasize the strategic value of mastering quantum physics concepts for technological and research progress.

Furthermore, S. Majidy's (2024) study entitled "Addressing misconceptions in university physics: A review and experiences from quantum physics educators" (30 citations) highlights significant challenges in addressing students' misconceptions. The complexity of quantum physics concepts, which often contradict logical thinking from everyday experience, causes confusion and cognitive conflict in students. This study underlines the need for effective pedagogical approaches to address this problem.

P. Nikolaus, M. Dželalija, & I. Weber (2024) with "Investigating Students' Conceptual Knowledge of Quantum Physics to Improve the Teaching and Learning Process" (26 citations) emphasize the importance of understanding students' conceptual knowledge as a basis for improving the teaching and learning process. In addition, J. Obbo, B. Dillmann, & D.P. Adorno (2024) present "A 5E-based learning experience to introduce concepts relevant in Quantum Physics" (21 citations), showing the application of a structured 5E learning model (Engage, Explore, Explain, Elaborate, Evaluate) to effectively introduce quantum physics concepts.

Finally, SN Azizah (2024) examined "The Influence of Quantum Teaching on Problem-solving skills in the Context of Lifelong Learning" (19 citations). Although the title specifically refers to "Quantum Teaching" which may differ from the subject of quantum physics, its focus on problem-solving skills and lifelong learning suggests broader relevance in the context of student competency development. Problem-solving skills are essential in quantum physics, where students are faced with complex and authentic problems that must be solved through exploration, collaboration, and critical thinking.

Overall, this analysis of the ten most cited articles confirms that research on the impact of using teaching materials in quantum physics instruction using problem-based learning models is very dynamic. Key trends that emerge are a focus on the development and evaluation of innovative and contextual teaching materials, the central role of problem-based learning models in developing critical thinking skills, and ongoing efforts to improve conceptual understanding and address misconceptions. The field continues to seek new ways, both through technology integration and curriculum adaptation, to make quantum physics more accessible and relevant to students.

The data obtained was then analyzed in Microsoft Excel and further processed using VOSviewer to produce a visual representation of the collected information. VOSviewer produces three types of data mapping: (1) network visualization, (2) overlay visualization, and (3) density visualization.

The visualization in the image above illustrates the connections between various circles, each representing a keyword from the articles. The proximity of one circle to another indicates the strength of the relationship between those keywords—the closer they are, the stronger the connection. The size of each circle reflects the frequency of the keyword's appearance in the title and abstract; the more frequently a keyword appears, the larger the circle and the font used to display it (Alifariki et al., 2022). The results of this network visualization are presented in Figure 3.

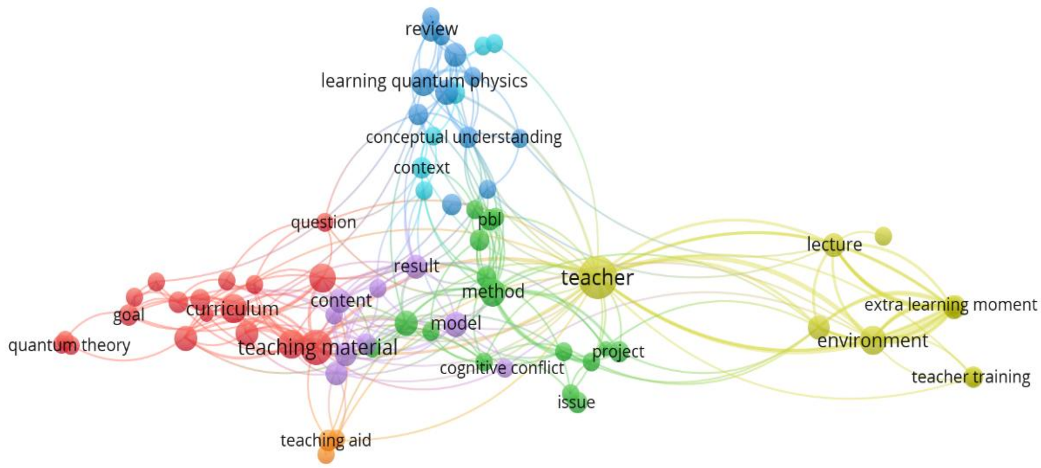

Figure 3. Visualization of Mapping Results in Network Visualization

Prominent circles in the visualization include keywords such as teacher, learning quantum physics, and teaching material. Alongside these larger circles, there are also several smaller ones. This in-depth VOSviewer visualization effectively reveals the multidimensional research landscape in physics education, specifically related to quantum physics, by grouping 35 terms into four major clusters that are interrelated and distinguished by color. The red cluster highlights conceptual foundations and curriculum design, centered on "quantum theory," "objectives," "content," and "teaching material" as the basic structure of education. The blue cluster focuses on innovative pedagogy and conceptual understanding, highlighting the process of "learning quantum physics" and achieving "conceptual understanding" through methods such as "PBL" (Problem-Based Learning) as well as the relevance of the learning "context." Meanwhile, the green cluster serves as the central core of the network, emphasizing the crucial role of "teacher," teaching "method," and pedagogical "model," while acknowledging the existence of "cognitive conflicts" and "issues" that pose challenges. Finally, the yellow cluster highlights the learning environment and professional development of teachers, including "lectures", "extra learning moments", supportive "environment", and the vital role of "teacher training" for the sustainability of education. The "teacher" cluster visually appears to be the most connected central node, emphasizing the importance of the teacher's role in integrating curriculum, methods, and an effective learning environment. The strong linkages between "teaching material", "curriculum", and "conceptual understanding" further reflect the urgency of developing contextual teaching materials to enhance the understanding of abstract concepts such as quantum physics, a finding that is in line with recent studies that emphasize curriculum innovation and teacher training in addressing students' misconceptions in modern physics.

The analysis of publication trends over the years related to a specific research topic is referred to as recency. In this context, the relevance of a research topic or theme is associated with the year in which the study was conducted. This is reflected through the color differentiation in each study's visualization. Darker colors in the overlay visualization indicate older research, while lighter or brighter colors suggest that the topic is currently trending or represents more recent studies (Komedi, 2022). The color gradient visually represents the timeline of the research, where shades closer to yellow indicate newer studies. The mapping results based on overlay visualization are shown in Figure 3.

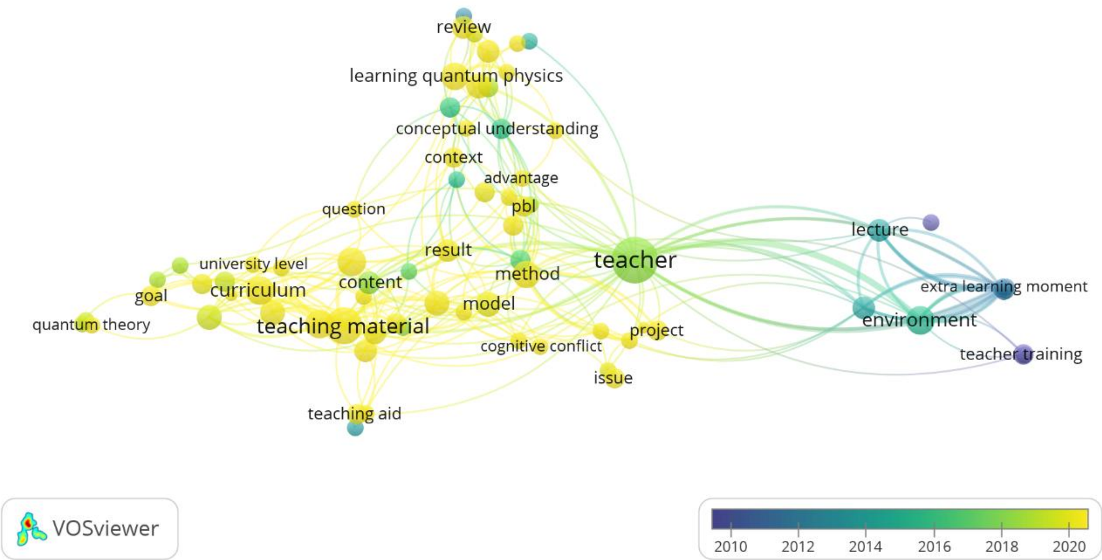

Figure 4. Visualization of Mapping Results on Overlay Visualization

In Figure 4, the grouping of articles is based on their most recent year of publication. The yellow color indicates that the study is currently ongoing or represents recent research. The VOSviewer visualization overlay image shows the temporal evolution of research related to quantum physics teaching, with a color gradient from blue (old) to yellow (new) representing the year of publication. Keywords such as “teacher training,” “lecture,” and “environment” appear earlier (2010–2015), indicating the initial focus of research on traditional approaches and structural support in teaching. Meanwhile, keywords such as “conceptual understanding,” “PBL,” and “cognitive conflict” appear in a more yellow color, indicating a recent trend (2018–2020) focusing on constructivist approaches and problem-based learning. The term “teacher” remains central to the interconnected themes, indicating the central role of teachers in adapting curricula, strategies, and teaching materials to support the understanding of complex physics concepts. This evolution reflects a shift from conceptual and curricular foundations to more innovative pedagogical approaches, teacher professional development, and optimization of the learning environment.

In the density visualization mapping, colors such as blue, green, and yellow are used to represent keyword frequency. Areas highlighted in yellow indicate high keyword popularity due to their frequent occurrence. As the color shifts toward green or blue, it signifies that the topic is less commonly researched, suggesting potential opportunities for future studies. The results of the density visualization mapping are illustrated in Figure 4.

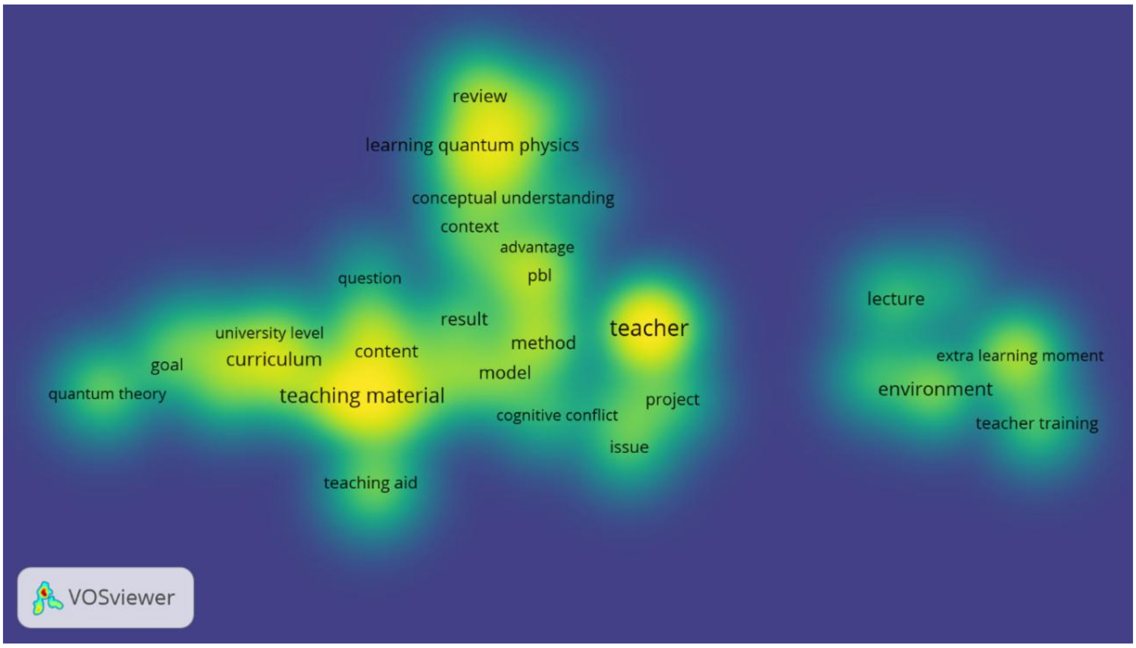

Figure 5. Visualization of Mapping Results in Density Visualization

This is illustrated in Figure 5, This density visualization image from VOSviewer displays the frequency density of keyword occurrences in quantum physics learning literature, with yellow indicating areas with the highest research intensity. It can be seen that the terms “teacher”, “teaching material”, and “curriculum” dominate the density center, confirming that the main focus of research is on pedagogical aspects, teaching material development, and the role of teachers. Keywords such as “conceptual understanding”, “PBL”, and “model” appear in medium-density areas, indicating a growing research trend in innovative learning strategies. Meanwhile, terms such as “teacher training” and “environment” are in low-density areas, but remain closely connected, indicating the importance of supporting aspects in effective learning processes.

The results of the bibliometric analysis show that pedagogical aspects, contextual teaching materials, and teacher involvement are dominant elements in quantum physics learning research during 2015–2025. This finding is consistent with the study of Vygotsky's constructivism theory which emphasizes the importance of scaffolding and the role of teachers in building students' conceptual understanding. The use of the problem-based learning (PBL) model, which has been shown to improve critical thinking skills (Saputri & Wisudawati, 2025), is a strong trend as shown by the density of the keywords "PBL" and "conceptual understanding" in the VOSviewer visualization. In addition, the use of analogies from classical physics as a bridge to abstract quantum concepts is also supported by research by Rodrigues et al. (2025), in line with the contextual-based cognitive approach. Learning technologies such as immersive VR (Mufit et al., 2024) also show significant contributions in reducing student misconceptions (Majidy, 2024) and increasing learning engagement, supporting Paivio's dual coding theory which suggests that combining visuals and verbals is effective in understanding difficult concepts. Studies by McAfee et al. (2025) and Şahin & Kılıç (2024) also confirmed that innovative project-based learning strategies and guided exploration proved to be more effective than conventional approaches. Curricularly, adjustments to ILIC and OBE policies (Irvani et al., 2024) indicate a shift in higher education towards competency-based learning outcomes and lifelong learning (Azizah et al., 2024). Therefore, these results not only reflect research trends but also emphasize the importance of integrating learning theory, technological innovation, and educational policy in developing more effective and relevant quantum physics teaching.

The main findings of this analysis show that in the period 2015–2025, publications on quantum physics learning have increased significantly, especially since 2021, with a dominant focus on the development of contextual teaching materials, the use of problem-based learning (PBL) models, and the increasing role of teachers as learning facilitators. Bibliometric visualization through VOSviewer reveals that keywords such as teacher, teaching material, and curriculum are central to the co-word map, indicating that quantum physics teaching is highly dependent on the quality of pedagogical interventions and adaptive curriculum design. In addition, the evolution of recent topics reflects a shift in approach from lecture methods to project-based and cognitive constructivist approaches, as seen from the emergence of keywords such as conceptual understanding, model, and cognitive conflict in the overlay and density visualizations. The increasing use of technologies such as VR and the 5E approach also shows digital integration in the learning process to strengthen the representation of abstract concepts. Thus, this study confirms that the success of quantum physics teaching is largely determined by the synergy between relevant teaching materials, active learning strategies, and the role of teachers who are oriented towards facilitating conceptual understanding.

This study has several limitations that need to be considered for interpretation and development of further studies. First, the data source only comes from Google Scholar through the Publish or Perish application, which although rich, does not necessarily cover all high-quality scientific publications indexed in databases such as Scopus or Web of Science. Second, the bibliometric analysis conducted is quantitative and does not include an in-depth review of the contents of the articles analyzed, so it does not fully describe the pedagogical complexity or context of implementation in the classroom. Third, although using VOSviewer for visual mapping, the interpretation of the co-word map is exploratory and requires additional validation through qualitative studies or educational experiments. In addition, the research time span until 2025 risks including data from articles that have not received enough citations or scientific feedback, so that its representation may be less stable. Therefore, the findings in this study should be used as an initial map that guides further research with a mixed approach and enrichment of data sources.

CONCLUSION

The results of this study indicate that the use of contextually designed teaching materials and the implementation of the Problem-Based Learning (PBL) model play a crucial role in enhancing the effectiveness of quantum physics instruction. Through a bibliometric analysis of 100 articles published between 2015 and 2025, it was found that topics such as the use of classical physics analogies, the development of PBL-based modules, and the utilization of immersive technologies like virtual reality are significant trends in quantum physics education research. The bibliometric visualizations reinforce the finding that "teaching material" and "learning quantum physics" are major focuses in the literature, while aspects like "conceptual understanding" and its connection with PBL remain relatively underexplored. Thus, this study highlights a substantial opportunity to deepen research on conceptual understanding and the integration of PBL models within the context of quantum physics instruction. These findings are expected to serve as a foundation for developing more innovative and transformative learning strategies in physics education.

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