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Trends in Project-Based Learning for Developing Critical Thinking Skills in Science Education: A Bibliometric Review

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Abstract: This study examines the role of Project-Based Learning (PjBL) in enhancing critical thinking skills in science education, focusing on research published from 2019 to 2024. The primary objective is to analyze trends in the literature related to PjBL and its impact on students' critical thinking, with an emphasis on integrating Science, Technology, Engineering, and Mathematics (STEM) education. A bibliometric approach was used, analyzing data from academic databases such as Scopus and Google Scholar, using tools like Publish or Perish 8 and VOSviewer. The results show a significant increase in publications on PjBL, particularly regarding critical thinking and STEM integration. Key themes such as problem-solving, collaboration, and the use of digital tools have gained prominence. The study also highlights the growing interest in technology-enhanced PjBL, especially in hybrid and online learning environments. PjBL is shown to effectively foster critical thinking by engaging students in real-world, inquiry-based projects. Future research should explore the role of digital tools in PjBL and its long-term impact on students' problem-solving abilities.

Keywords: Bibliometric analysis; Critical thinking skills; Project-based learning (PjBL); Science education; STEM integration

Introduction

In the 21st century, education systems across the world are tasked with preparing students to meet the complex challenges of an increasingly interconnected and rapidly changing global landscape (Assefa, 2024; Malik, 2018). The need for students to develop critical thinking skills has never been more urgent. Critical thinking—the ability to analyze, evaluate, and synthesize information, and to make reasoned decisions based on evidence—is central to the modern educational agenda, especially in science education (Zawacki-Richter et al., 2019). This demand is driven by the recognition that in an era of vast information, individuals must not only acquire knowledge but also develop the ability to question, solve problems, and make informed decisions (Darling-Hammond et al., 2020). In the context of science education, critical thinking enables students to understand and engage with scientific concepts, apply them in problem-solving situations, and contribute meaningfully to discussions about global challenges such as climate change, technological advancements, and public health issues (Kumar et al., 2023; Oliver et al., 2020).

Science, Technology, Engineering, and Mathematics (STEM) education is widely regarded as an essential means of achieving these educational goals. STEM education equips students with the skills and knowledge required to thrive in the modern workforce, which is increasingly focused on innovation, problem-solving, and technical expertise (Han et al., 2015). In recent years, educational policymakers have increasingly emphasized the integration of critical thinking and STEM within educational frameworks, advocating for more engaging, problem-based, and inquiry-driven learning approaches (Blumenfeld et al., 1991). As a result, many educational systems have turned toward methods that provide students with

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opportunities for active learning, particularly those that encourage problem-solving and critical thinking in real-world contexts.

Project-Based Learning (PjBL) has emerged as one of the most widely discussed and implemented educational strategies to address this need. PjBL is a student-centered pedagogical approach that involves students working collaboratively on long-term projects that require them to apply their knowledge and skills to solve real-world problems (Blumenfeld et al., 1991). This model differs from traditional methods of instruction, which typically prioritize rote memorization and passive learning, by focusing on the process of learning through hands-on experiences, inquiry, and problem-solving. Research has consistently shown that PjBL enhances students' critical thinking, collaboration, and communication skills, all of which are essential competencies in the modern world (English et al., 2013). Furthermore, PjBL fosters the development of 21st-century skills such as creativity, adaptability, and the ability to collaborate with diverse groups of people, making it particularly relevant for preparing students to succeed in a globalized and technologically advanced society (Hebebci et al., 2022; Hiğde et al., 2022; Mater et al., 2022).

In science education, PjBL offers an innovative approach that encourages students to engage deeply with scientific concepts by working on projects that mimic real scientific inquiry. Students might design experiments, collect and analyze data, and present their findings, thereby practicing the scientific method in a contextual and experiential way (Sadeh et al., 2009). This approach aligns closely with the goals of science education, which are not only to impart factual knowledge but also to cultivate skills that will enable students to critically evaluate scientific evidence and make informed decisions. By emphasizing the application of knowledge rather than the memorization of facts, PjBL enhances students' problem-solving abilities and promotes a deeper understanding of scientific principles (Apriliani et al., 2019).

However, while PjBL has proven effective in enhancing student engagement and improving learning outcomes in various subjects, its implementation in science education remains an area of active research. There is an increasing body of literature examining the impact of PjBL on students' critical thinking skills and academic achievement in science education (Doyan et al., 2024; Han et al., 2015). For instance, research has shown that students who participate in PjBL experience greater improvement in their problem-solving abilities and display a stronger understanding of scientific concepts compared to those who engage in more traditional forms of instruction (Blumenfeld et al., 1991). Moreover, studies have indicated that PjBL supports the development of collaborative learning skills, which are essential for success in the modern workplace (English et al., 2013).

Despite these positive outcomes, the widespread adoption of PjBL in science classrooms is hindered by several challenges. One of the primary barriers is the need for significant changes in instructional practices, teacher training, and curriculum design. Teachers must be adequately prepared to facilitate PjBL effectively, which involves not only guiding students through the stages of a project but also providing the appropriate resources and scaffolding for students to work independently (Blumenfeld et al., 1991). Additionally, the assessment of students' performance in PjBL can be complex, as it requires evaluating not only the final product but also the process of learning, collaboration, and critical reflection throughout the project (Sadeh et al., 2009).

Another challenge is the need for adequate support in terms of technology and resources. Although PjBL can be implemented with limited resources, the integration of technology into project-based learning enhances the quality of the learning experience. The use of digital tools—such as simulations, interactive e-books, and online collaboration platforms—has been shown to support students' engagement and critical thinking skills by providing them with access to dynamic content and real-time data (Stolpe et al., 2024). The integration of such tools into science education has the potential to transform how students interact with scientific concepts, making learning more interactive, immersive, and relevant to real-world (Firdausy et al., 2020).

Despite these challenges, the potential benefits of PjBL in improving critical thinking skills in science education are substantial. The growing body of research suggests that when implemented effectively, PjBL fosters an environment where students are encouraged to think critically, work collaboratively, and apply their knowledge to solve authentic problems. This approach is particularly relevant in the context of STEM education, where critical thinking and problem-solving are core skills that students must develop to succeed in both academic and professional settings (Han et al., 2015). Therefore, further research into the specific mechanisms by which PjBL influences critical thinking in science education is essential for improving instructional practices and maximizing the impact of this approach.

This study aims to analyze the trends in research related to the use of Project-Based Learning (PjBL) in enhancing critical thinking skills in science education from 2019 to 2024. Using a bibliometric approach, the study will identify key themes, sources of publication, and dominant keywords associated with PjBL in the context of science learning. The findings of this study will provide insights into the current state of research on

PjBL, highlight areas that remain underexplored, and suggest directions for future research to further explore the potential of PjBL to foster critical thinking and problem-solving in science education.

In sum, this research seeks to contribute to the growing body of literature on PjBL by exploring its role in enhancing critical thinking skills and providing a detailed bibliometric analysis of the existing body of research. The results will inform educators and policymakers about the potential of PjBL to improve science education and prepare students for the challenges of the 21st century.

Method

This section outlines the research design, data collection methods, and analytical techniques used in this study. The methodology follows a bibliometric approach, which is suitable for analyzing large-scale academic literature and identifying key trends, thematic clusters, and relationships within a body of research (Hallinger et al., 2019). By employing bibliometric analysis, the study aims to systematically evaluate the development and trends in Project-Based Learning (PjBL) related to critical thinking skills in science education over the period from 2019 to 2024.

Research Design

This study employs a quantitative bibliometric analysis to map the existing body of literature on the integration of Project-Based Learning (PjBL) in science education and its influence on students' critical thinking skills. Bibliometrics, as defined by Hallinger et al. (2019), refers to the use of statistical and mathematical methods to analyze academic publications. This method allows for the identification of patterns, trends, and the relationships between different research themes over a specified time period. Bibliometric analysis is particularly effective for uncovering the intellectual structure of a field and visualizing how scholarly activity evolves over time (Zawacki-Richter et al., 2019).

By using bibliometric tools such as VOSviewer and Publish or Perish 8, the study generates a comprehensive overview of the research landscape in the field of PjBL in science education, focusing on trends in publication volume, keyword clustering, and the collaborative network among authors and institutions (Rafols, 2014).

Data Collection

The data collection process involved extracting bibliographic information from several well-established academic databases. These databases include Scopus, Google Scholar, and Dimensions, which are widely recognized for their comprehensive coverage of academic journals, conference proceedings, and other scholarly publications in the field of education and science (Hallinger et al., 2019).

The data were collected using specific search queries designed to capture relevant literature on the following topics: Project-Based Learning (PjBL); Critical Thinking Skills; Science Education; STEM Education (Science, Technology, Engineering, and Mathematics).

The time frame for the study was 2019 to 2024, focusing on recent developments in PjBL and its impact on science education. The search queries were designed to include articles, conference papers, and books that focus on these central topics, ensuring that the analysis would be comprehensive and representative of the current state of research. According to Hallinger et al. (2019), this approach ensures that the study includes both peer-reviewed articles and conference proceedings, which are key sources for tracking emerging research trends.

After conducting the search, irrelevant articles (e.g., those outside the scope of PjBL in science education or those not related to critical thinking development) were excluded from the analysis based on predefined inclusion and exclusion criteria. Only articles published in English or Indonesian and within the specified time period were retained.

Data Analysis

The collected data were analyzed using two primary bibliometric tools: Publish or Perish 8 and VOSviewer. Both tools allow for an in-depth examination of citation patterns and network structures in academic research, making them suitable for identifying trends, key authors, journals, and keywords.

Publish or Perish 8: This tool was used to extract citation data and bibliographic information from Google Scholar. Publish or Perish generates detailed citation metrics, including the h-index, i10-index, and citation counts, which are important for identifying influential publications and measuring the impact of specific articles in the field of PjBL and critical thinking in science education (Gusenbauer, 2024; Harzing, 2019; Martín-Martín et al., 2021). It also provided the raw bibliometric data that were used to generate the visualizations in the subsequent analysis.

VOSviewer: This tool was used to create visualizations of the bibliometric data, particularly keyword clusters and network visualizations. VOSviewer is designed for the visualization of complex bibliometric networks, such as those representing relationships between authors, keywords, and research themes (Rafols, 2014). The tool allows for the identification of research clusters based on keyword co-occurrence, helping to map the intellectual structure of the field of PjBL in science education. This approach helps identify key themes, such as critical thinking,

collaboration, and problem-solving, that are central to the research on PjBL.

The analysis in this study is structured as follows: (a) Keyword co-occurrence: Identifying the most frequently appearing keywords and grouping them into thematic clusters to discern the major areas of focus within the field. (b) Temporal analysis: Mapping how the frequency of keywords has evolved over time, highlighting the emergence of new themes, such as STEM integration and digital tools in PjBL, as the field develops. (c) Citation and author network analysis: Identifying key researchers, influential papers, and research collaborations within the domain of PjBL and critical thinking skills in science education.

Visualization Techniques

To complement the bibliometric analysis, visualization techniques were employed to illustrate the findings. VOSviewer provided several types of visualizations, including:

Overlay visualizations: These show the temporal evolution of keywords and concepts in the literature. The color scheme indicates the years in which terms were most frequently cited, helping to identify emerging trends (Rafols, 2014).

Density visualizations: These highlight the density of specific topics within the literature, indicating areas with the highest concentration of research activity (Rafols, 2014).

Network visualizations: These display the relationships between authors, institutions, and keywords, allowing the identification of collaborative networks and research clusters (Harzing, 2019).

These visualizations serve not only to summarize the data but also to provide a clearer understanding of how different research areas within PjBL in science education are interrelated and evolving.

Ethical Considerations

This study strictly adhered to ethical guidelines in the use of bibliometric data. The bibliographic data used in this study were publicly available through academic databases and were analyzed without any modification. As this research does not involve human participants or sensitive data, ethical approval was not required. All references to authors and publications in the study were appropriately cited to maintain academic integrity.

Limitations

While bibliometric analysis provides valuable insights, it is not without its limitations. One of the main limitations of this study is the reliance on citation counts and keyword analysis, which may not fully capture the quality or depth of the research in the field. Bibliometric tools are also limited by the quality of the underlying databases, and some research might not be indexed in the sources used, particularly non-English language publications or conference proceedings that are not widely disseminated (Gusenbauer, 2024; Harzing, 2019; Martín-Martín et al., 2021). Additionally, the focus on keywords may miss broader themes that are important but do not appear frequently in the literature.

Result and Discussion

Product This section presents the findings of the bibliometric analysis and discusses the implications of these results in the context of Project-Based Learning (PjBL) in science education, particularly in enhancing students' critical thinking skills. The analysis identifies key trends in the literature, provides an overview of the most frequently cited authors and journals, and highlights the thematic clusters that define the field of PjBL as it pertains to critical thinking and science education. Additionally, the section explores the temporal evolution of research topics and the relationships between these topics, drawing on the findings from the Publish or Perish 8 and VOSviewer tools.

Trends in Research Publications

The bibliometric analysis revealed a significant increase in publications on PjBL in science education between 2019 and 2023, particularly in the context of enhancing critical thinking skills. The number of published articles peaked in 2023, reflecting an increasing interest in PjBL as a pedagogical tool to foster critical thinking in science learning (Figure 1). The growing number of publications aligns with the findings of Zawacki-Richter et al. (2019), who observed a similar trend in educational research, suggesting that PjBL has gained substantial traction as an effective method for improving students' problem-solving abilities and analytical thinking.

This rise in publications is consistent with broader educational trends emphasizing active learning, inquiry-based learning, and project-based pedagogy as essential strategies for promoting higher-order cognitive skills (Blumenfeld et al., 1991). Additionally, the increase in PjBL research is likely influenced by policy shifts that prioritize the development of 21st-century skills—including critical thinking, collaboration, and problem-solving—within educational frameworks (Han et al., 2015).

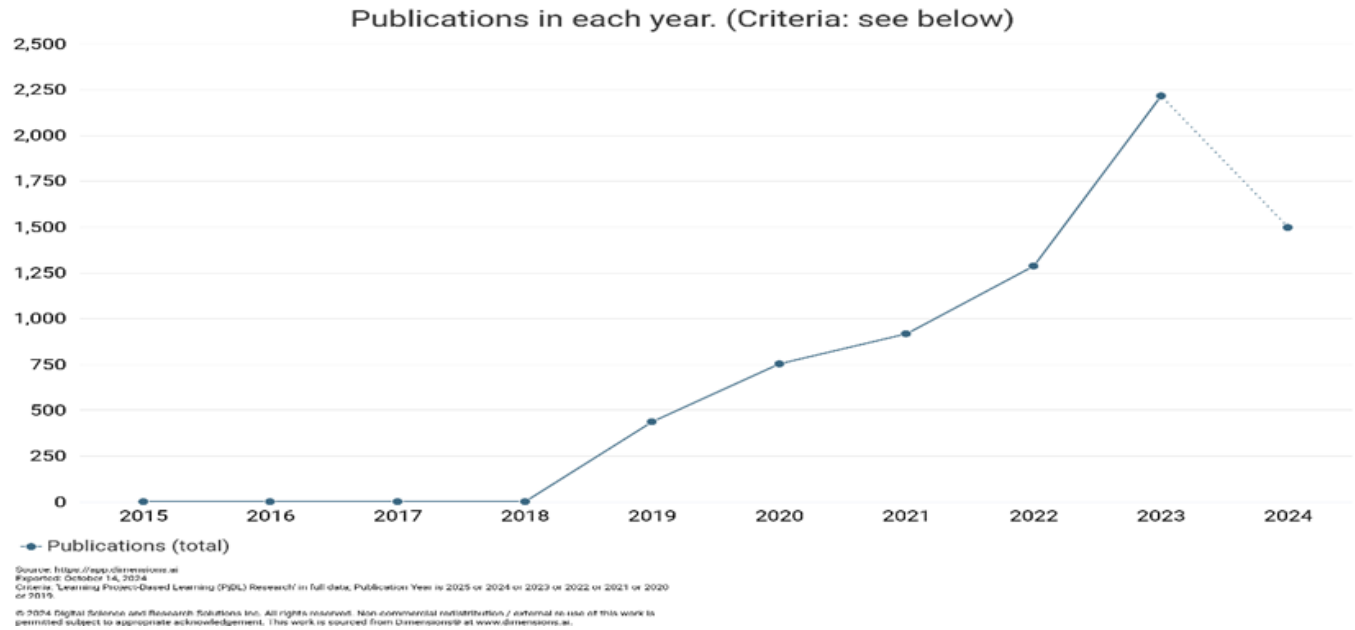

Figure 1. Annual publication trends on PjBL and critical thinking in science education (2019–2024)

Primary Sources of Publication

The analysis identified several journals that dominate the field of PjBL and critical thinking in science education. Jurnal Penelitian Pendidikan IPA and Advances in Social Science, Education, and Humanities Research were among the top journals publishing research on PjBL, with a combined total of over 450 articles on the topic (Table 1). These journals highlight the interdisciplinary nature of PjBL research, as the topic spans across education, science, and social science disciplines.

Table 1. Top Journals Publishing Articles on PjBL in Science Education

Rank	Journal Name	Publications
1	Jurnal Penelitian Pendidikan IPA	317
2	Advances in Social Science, Education, and Humanities Research	150
3	Jurnal Basicedu	86
4	Edukatif Jurnal Ilmu Pendidikan	78
5	Journal of Physics Conference Series	69

The dominance of journals like Jurnal Penelitian Pendidikan IPA suggests that research on PjBL in science education is particularly strong in Indonesia, reflecting the growing interest in improving science education practices in this region. Furthermore, the presence of journals from various educational disciplines indicates that PjBL is considered a versatile approach, relevant to a broad range of educational contexts (Hebebci et al., 2022).

Thematic Clusters and Key Research Topics

The VOSviewer analysis revealed several thematic clusters within the literature on PjBL in science education. These clusters represent the primary research areas in the field. The most prominent themes identified include critical thinking, problem-solving, STEM integration, and collaborative learning (Figure 2). These clusters underscore the multifaceted role of PjBL in not only improving critical thinking skills but also in fostering the development of other 21st-century competencies.

The cluster on critical thinking (highlighted in red) is central to the analysis, indicating that most research on PjBL emphasizes its impact on fostering analytical skills. The problem-solving cluster (green) closely follows, showing that PjBL is viewed as an effective approach for helping students develop strategies to address real-world scientific problems. These findings are consistent with the work of Blumenfeld et al. (1991), who argued that PjBL provides a context for students to engage deeply with scientific inquiry, thereby enhancing their critical thinking and problem-solving abilities.

Moreover, the analysis highlights the STEM cluster (blue), which shows that much of the recent research on PjBL focuses on its integration with STEM education. As noted by Han et al. (2015), integrating PjBL with STEM subjects allows students to engage with science in a more holistic and applied manner, reinforcing both theoretical knowledge and practical skills. This thematic focus on STEM integration is a growing trend in educational research, reflecting the increasing demand for educational approaches that prepare students for the challenges of the global workforce (Halawa et al., 2024; Wan et al., 2022).

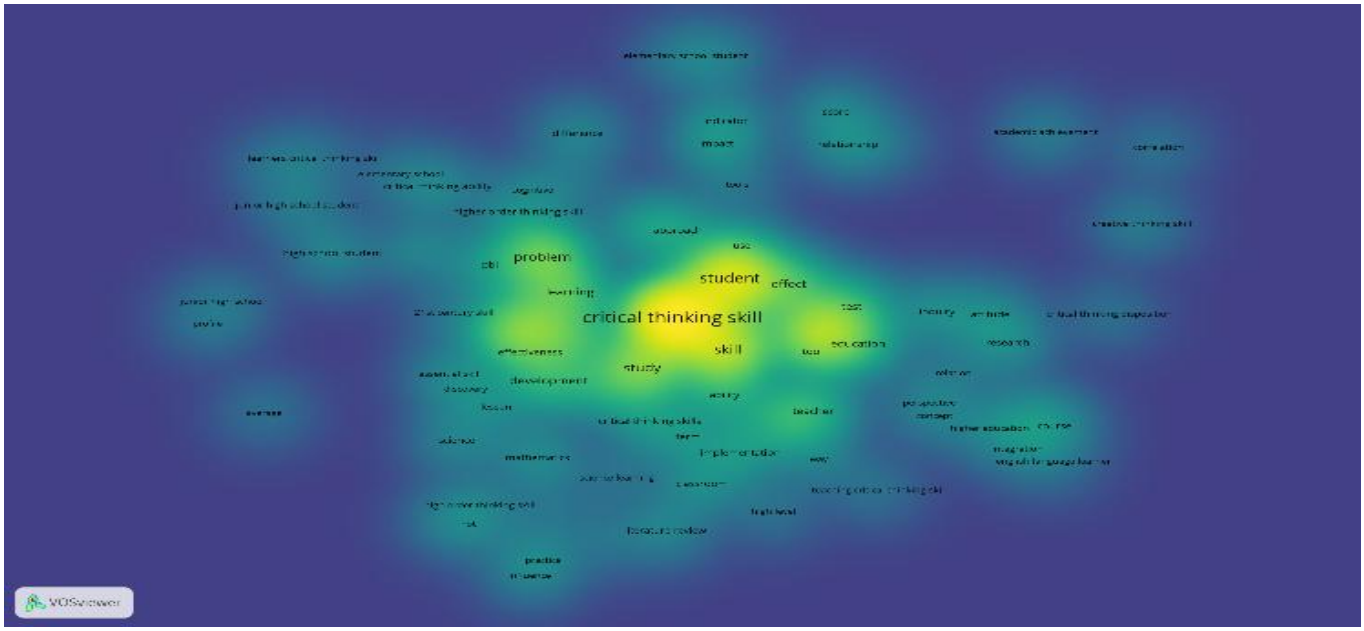

Figure 2. Visualization of thematic clusters in PjBL and critical thinking literature

Temporal Evolution of Research Topics

The overlay visualization (Figure 3) provides insights into the temporal evolution of key research topics in PjBL. The most notable shift over time is the increasing emphasis on the use of digital tools in PjBL to enhance science education. Keywords such as "digital tools", "online collaboration", and "virtual learning environments" emerged prominently in the later years of the analysis (2022–2024). This reflects the growing role of technology in education, which has been accelerated by the COVID-19 pandemic and the subsequent shift to online and hybrid learning environments (Bond et al., 2024; Zawacki-Richter et al., 2019).

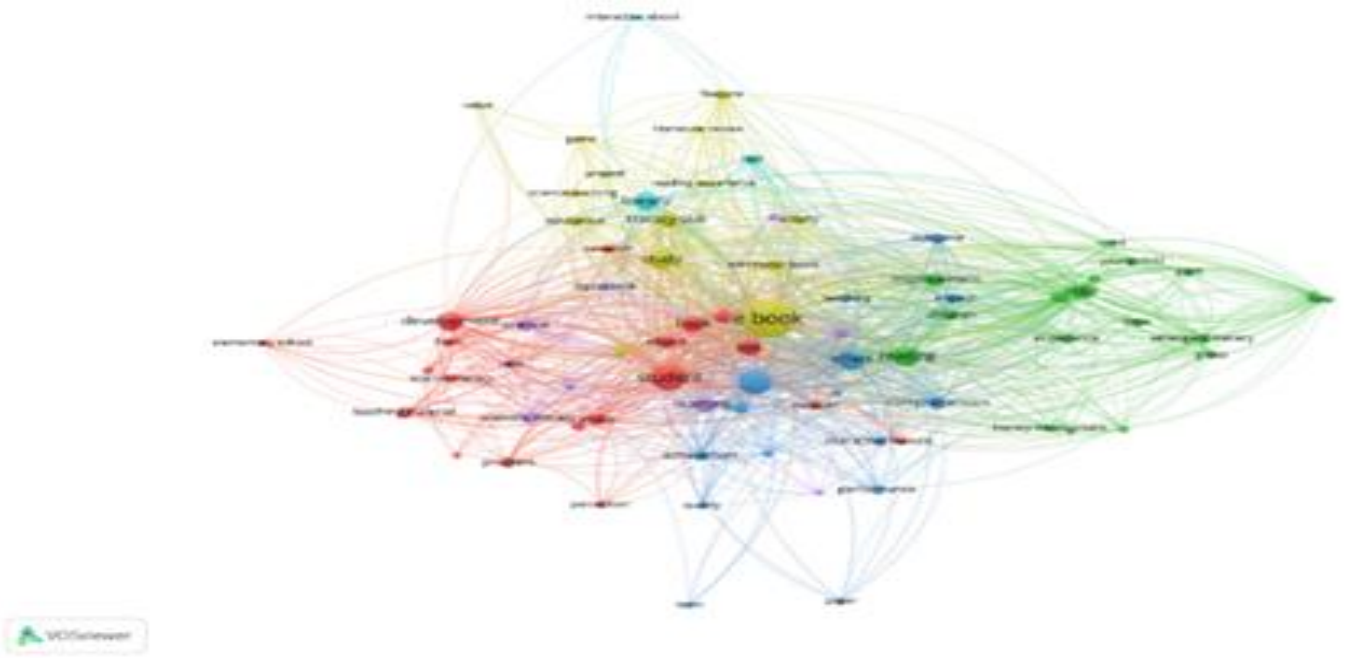

Figure 3. Overlay visualization showing temporal evolution of keywords

The emergence of terms related to digital tools indicates that PjBL in science education is increasingly incorporating technology-enhanced learning (TEL) to facilitate remote collaboration, access to scientific simulations, and engagement with interactive content. This is consistent with (Stolpe et al., 2024), who

emphasized the role of digital tools in enhancing students' critical thinking and problem-solving skills by offering more immersive and interactive learning experiences.

Citation and Author Network Analysis

The network visualization (Figure 4) reveals the relationships between key authors and institutions involved in PjBL research. The visualization shows a dense network of collaboration among researchers, particularly those from higher education institutions focused on science and education. Blumenfeld et al. (1991), Zawacki-Richter et al. (2019), and Hebebci et al. (2022) emerge as central authors in the field, indicating their significant contributions to the development of PjBL research, especially in the context of critical thinking and problem-solving in science education.

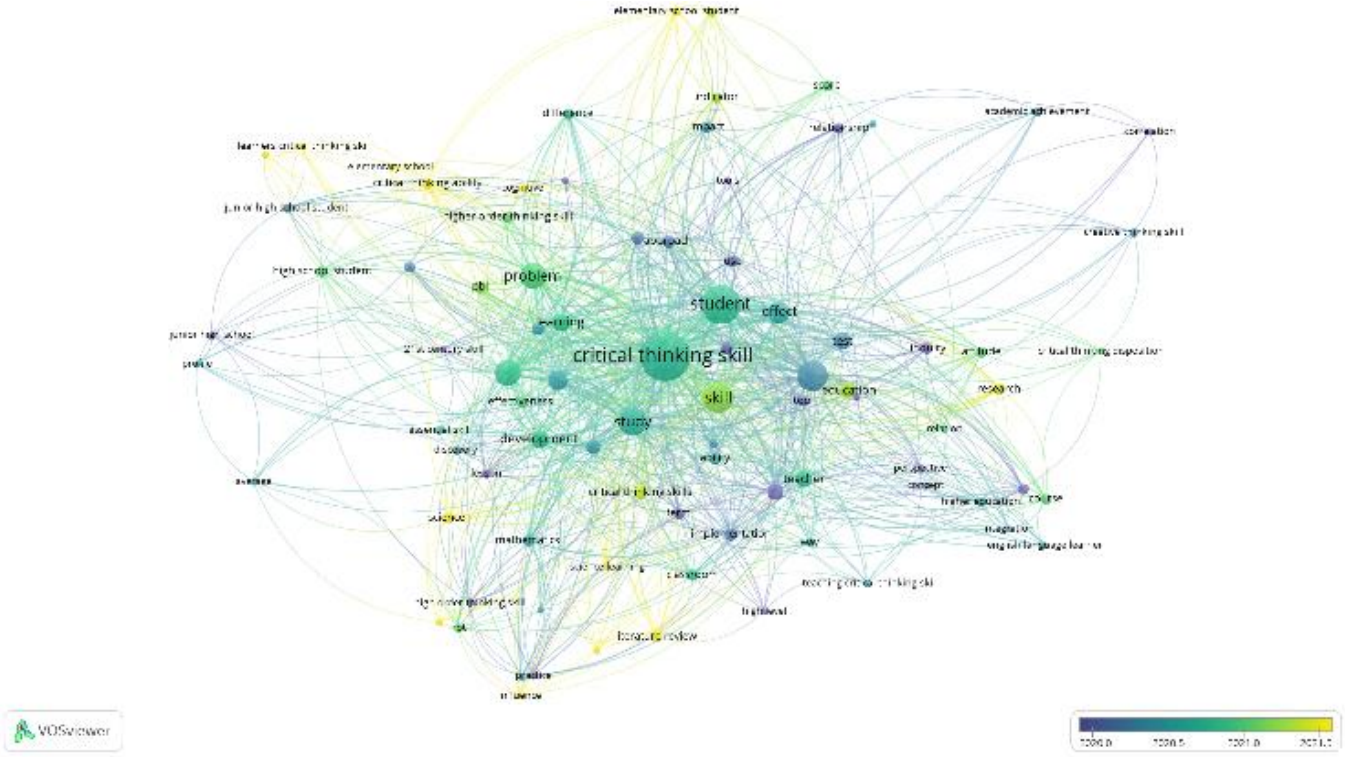

Figure 4. Network visualization of citation and author collaboration in PjBL research

The dense network of collaboration suggests that PjBL research is highly interdisciplinary, drawing on expertise from educational psychology, pedagogy, and science education. These findings align with the work of Sadeh et al. (2009), who emphasized the importance of collaborative inquiry in project-based learning, which allows students to engage with science in a meaningful and contextually relevant manner.

Implications for Research and Practice

The findings of this bibliometric analysis have significant implications for both research and practice. From a research perspective, the increasing integration of digital tools and STEM in PjBL offers promising avenues for future studies, particularly in exploring the effectiveness of technology-enhanced PjBL in fostering critical thinking in diverse educational settings. Future research could also examine the impact of interdisciplinary collaboration in PjBL, as it is clear that cross-disciplinary research is vital for advancing the field.

From a practical standpoint, educators are encouraged to consider integrating digital tools into PjBL, particularly in the context of remote learning and hybrid classrooms. The findings suggest that technology-enhanced PjBL not only supports critical thinking but also helps students engage with scientific content in more interactive and applied ways, making learning more relevant and meaningful.

Conclusion

This study highlights the increasing role of Project-Based Learning (PjBL) in enhancing critical thinking skills in science education, as reflected in the growing number of publications from 2019 to 2024. The findings reveal a strong association between PjBL, STEM integration, and the use of digital tools, underscoring its effectiveness in fostering problem-solving,

collaboration, and analytical skills. The study also emphasizes the adaptability of PjBL, particularly in response to shifts in educational environments, such as the transition to remote and hybrid learning. While providing valuable insights into research trends and thematic developments, the study acknowledges its limitations, particularly in assessing the depth and quality of individual studies. Future research should explore qualitative aspects of PjBL implementation, its long-term impact on students' critical thinking, and the potential of digital technologies to further enhance learning outcomes. As PjBL continues to evolve, its role in shaping 21st-century science education remains crucial, with opportunities for further innovation and interdisciplinary exploration.

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All authors declare that they have no conflict of interest.

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