

Scientific Mapping Research on the Integration of the PjBL Model and Sustainable Development: A Bibliometric Analysis

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ABSTRACT

This study examines the trajectory of research on the integration of Project-Based Learning (PjBL) and Education for Sustainable Development (ESD) in advancing 21st-century competencies. A bibliometric approach was applied using Scopus-indexed publications from 2010 to 2025, analyzed through VOSviewer with network, overlay, and density visualizations. The findings indicate a substantial increase in publication output, particularly after 2020, reflecting growing academic interest in sustainability-oriented learning. The results also reveal a multidisciplinary expansion covering higher-order thinking, collaborative learning, curriculum development, and technological integration, alongside a shift toward more contextual and complex pedagogical approaches. The research landscape is dominated by contributions from social sciences and developed countries, although developing countries show increasing participation. In terms of competencies, PjBL mainly promotes critical thinking, while ESD emphasizes creativity and innovation. However, the dominance of non-quartile publications highlights the need to improve methodological rigor and strategic publication practices.



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INTRODUCTION

The advancement of science and technology requires education systems to prioritize 21st-century skills. Critical thinking, creativity, communication, and collaboration serve as essential foundations for addressing global challenges. The implementation of student-centered learning approaches enhances active engagement through exploration, analysis, and contextual problem-solving activities (Nurhayatii et al., 2025). Student-centered learning promotes active engagement through exploration and problem-solving. Therefore, strengthening these skills is crucial for developing competent human resources prepared for future demands.

Education for Sustainable Development (ESD) is a global agenda that positions education as a key driver in achieving a sustainable society while promoting the development of knowledge, skills, values, and attitudes to support sustainability (Fernando & Tajan, 2024). ESD plays a crucial role in achieving the SDGs, particularly Goal 4 on inclusive and quality

education (Holst et al., 2024). Therefore, integrating sustainability principles into learning serves as a key strategy to enhance learners' awareness and participation in addressing global challenges. Therefore, the implementation of ESD has become one of the key strategies for advancing the transformation of twenty-first-century education (Faizah et al., 2026).

Physics education supports sustainable development through its close connection with energy, the environment, and technology. It enhances conceptual understanding while developing analytical and problem-solving skills based on scientific reasoning (Nurdiansyah et al., 2026). The integration of sustainability principles enables learners to connect concepts with real-world contexts and fosters critical thinking and environmental awareness, thereby contributing to the implementation of ESD (Novita et al., 2025).

Project-Based Learning (PjBL) is a learner-centered instructional model that engages students in completing projects based on authentic, real-world problems. This model effectively promotes the development of critical thinking, creativity, communication, and collaboration, which are regarded as essential competencies for twenty-first-century learning (Satria et al., 2025). In the context of physics education, PjBL facilitates students in connecting scientific concepts with real-life phenomena while enhancing their problem-solving abilities. The integration of PjBL with ESD is increasingly important as it contributes to strengthening competencies and raising awareness of sustainability-related issues (Nurdiansyah et al., 2026).

Research on the integration of PjBL and ESD has grown significantly in recent years. Studies highlight its effectiveness in enhancing learners' competencies while embedding sustainability principles in learning. Bibliometric evidence shows a consistent rise in publications, collaboration, and evolving research themes. Overall, this integration has become an increasingly important focus in educational research (Asrizal et al., 2025).

However, bibliometric research on the integration of PjBL and ESD remains limited. Most previous studies have focused on mapping the development of either PjBL and ESD as separate research domains, thus providing only a limited understanding of the integration between these two concepts (Rahmawati et al., 2025). Information regarding publication trends, collaboration networks, emerging research themes and future research directions opportunities has not yet been comprehensively examined. As a result, the overall direction and development of research on the integration of PjBL and ESD remain insufficiently understood. Therefore, a bibliometric study that systematically maps the integration of these two concepts is still highly needed (Fatmawati et al., 2026).

The increasing number of publications on the integration of PjBL and ESD indicates that this topic is gaining growing attention in educational research. However, research trends, the direction of scholarly development, as well as the dynamics of emerging and declining themes have not yet been comprehensively analyzed, resulting in a limited understanding of the evolution of this field. In addition, the identification of research gaps remains a crucial aspect in uncovering strategic and relevant research opportunities for the future more accurately. Therefore, the absence of a systematic analysis of the relationships among authors, institutions, countries, and keyword networks underscores the importance of employing bibliometric analysis to provide a comprehensive and data-driven mapping of the development of research on the integration of PjBL and ESD.

Bibliometric analysis is a quantitative method used to evaluate the development of a scientific field based on publication data. This method enables the identification of publication productivity, influential authors, institutions, countries, collaboration patterns, and the evolution of research themes (Öztürk et al., 2024; Syafri, 2026). The use of VOSviewer supports the systematic visualization of keyword relationships, author collaborations, and research trends. Thus, bibliometric analysis provides a comprehensive understanding and helps identify emerging topics and future research opportunities related to the integration of PjBL and sustainable development (Donthu et al., 2021; Hadiastriani & Djarot, 2024).

Research on the integration of PjBL and ESD requires comprehensive scientific mapping to clearly understand the development of this field. Bibliometric analysis is needed to examine publication trends, collaboration patterns, research themes, and future research directions, as well as to identify research gaps and opportunities (Fatmawati et al., 2026). This study analyzes publications from 2015 to 2025 using VOSviewer to visualize research developments. The findings are expected to serve as a reference for researchers and educators in developing ESD-based physics learning

METHODS

Research on the integration of PjBL and ESD was conducted using a descriptive quantitative bibliometric approach to systematically identify publication trends, thematic developments, and emerging research opportunities (Donthu et al., 2021). Relevant English-language articles published between 2010 and 2025 were retrieved from the Scopus database following PRISMA guidelines (Page, 2021). The search used the keywords “Project-Based Learning” AND “Sustainable Development” without limiting educational levels or subject areas. Journal quartiles (Q1–Q4) were then determined during post-processing using SCImago Journal Rank (SJR) metrics rather than Scopus filters.

Article metadata were exported in CSV format and analyzed using VOSviewer to visualize keyword networks and conceptual relationships (Kirby, 2023). Bibliometric analysis evaluated publication productivity, collaboration patterns, and thematic changes over time. It also identified influential works and the intellectual structure of the field. The results were interpreted using performance analysis and science mapping to provide a comprehensive overview of trends and future research directions on PjBL–ESD integration (Mondal, 2026).

The research followed a systematic bibliometric procedure, including keyword search, data collection, selection, analysis, visualization, and interpretation (Irawan et al., 2024). Only valid and relevant articles were analyzed, and the results were presented using tables, graphs, and network visualizations to illustrate trends, collaboration patterns, and thematic developments in PjBL and ESD research.

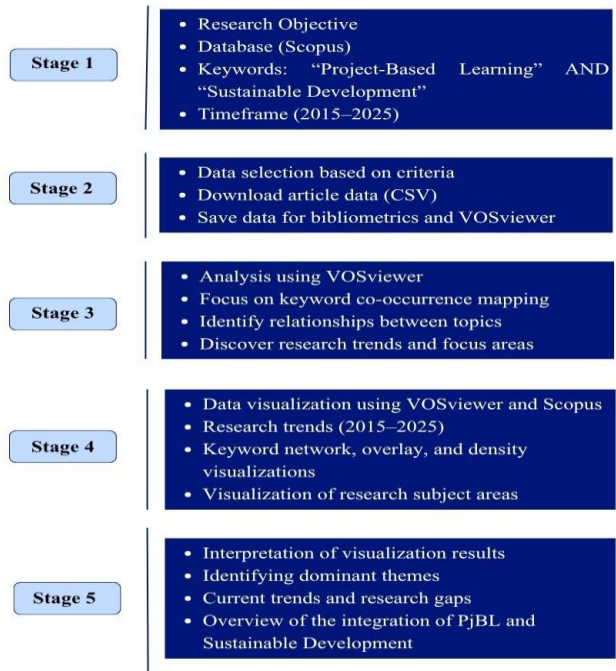


Figure 1. Stages in Bibliometric Analysis Research

The data processing stage was conducted after obtaining metadata from the Scopus database. The CSV data were processed using Microsoft Excel and Notepad for verification, selection, and keyword normalization. This included removing irrelevant data, correcting inconsistencies, and merging similar terms. As a result, the data became more accurate, consistent, and ready for bibliometric analysis.

The metadata were analyzed using VOSviewer and bibliometric tools to examine publication output, collaboration patterns, and research topic trends. VOSviewer was used to generate network, overlay, and density visualizations that illustrate keyword relationships, temporal trends, and topic intensity. These visualizations also reveal collaboration among authors, institutions, and countries. The results were then interpreted descriptively to identify publication trends, intellectual structures, and the direction of PjBL and ESD research.

RESULTS AND DISCUSSION

Results

The bibliometric analysis was applied to identify research trends in the integration of PjBL and ESD by examining publication productivity, distribution, collaboration patterns, sources, and topic mapping. The findings were interpreted to reveal conceptual relationships, evolving themes, and future research opportunities. This analysis also provides an overview of the intellectual structure and development of the field. Moreover, it offers practical insights for researchers, educators, and policymakers to support innovation and broader implementation in educational practice.

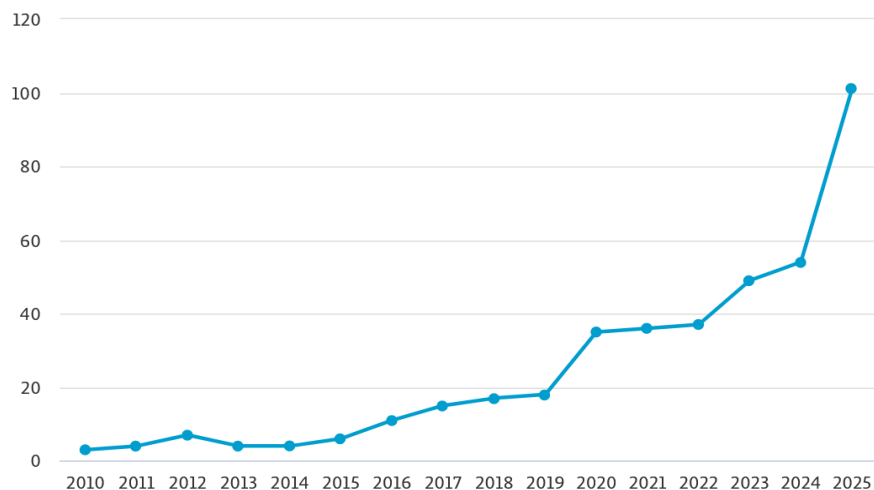


Figure 2. Distribution of Publication Trends 2010 to 2025

Figure 2 illustrates the trend of publications on the integration of PjBL and ESD from 2010 to 2025, which generally demonstrates an upward trajectory despite several fluctuations over time. In the initial phase (2010–2014), the number of publications remained relatively low, followed by a gradual increase that reached 18 documents by 2019, indicating an early stage of exploration and limited scholarly attention. A more substantial growth phase began in 2020, with a consistent rise in publication output through 2024, reflecting the growing recognition of the importance of integrating sustainability principles into innovative pedagogical approaches. The most notable surge occurred in 2025, when publications sharply increased to 101, suggesting a rapid expansion of research activity driven by global educational demands and sustainability agendas. This pattern also implies that researchers are increasingly focusing on student-centered and context-based learning models aligned with sustainable development

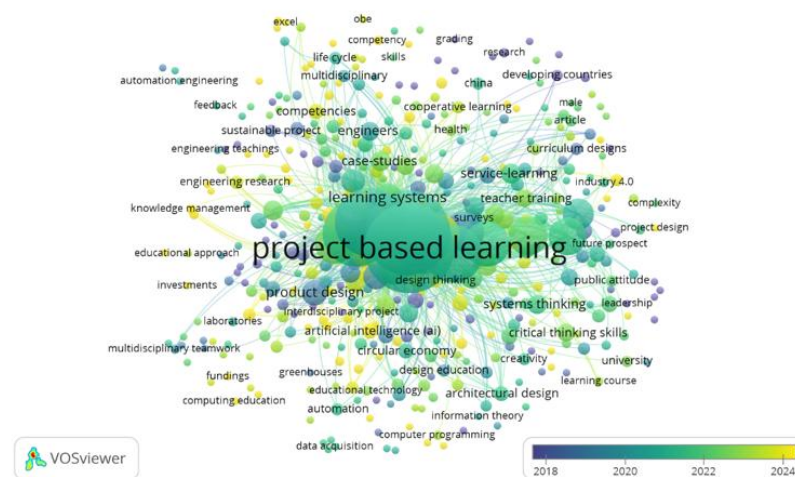


Figure 4. Visualization of the Overlay Between PjBL and ESD Integration in Education

Based on Figure 4, the overlay visualization shows the evolution of PjBL and ESD research topics through color variations representing the average year of keyword occurrence. Early research (blue–purple) focused on learning experiences and basic project design, followed by a shift (green) toward sustainability integration and higher-order thinking skills. Recent developments (yellow) emphasize advanced technologies such as artificial intelligence and the Internet of Things, along with more collaborative and innovative learning approaches. Overall, this trend reflects a move toward a multidisciplinary approach and highlights opportunities in physics education through contextual projects, digital integration, and the strengthening of 21st-century skills.

The fourth finding is derived from density visualization using VOSviewer, which highlights the intensity and relationships of keywords within the research network. High-density areas (yellow–green) indicate dominant themes such as project-based learning and education for sustainable development, while low-density areas (blue–purple) represent less prominent topics. This mapping helps identify core research focuses and the distribution of themes. Overall, it provides a clear overview of topic development in PjBL and ESD integration research.

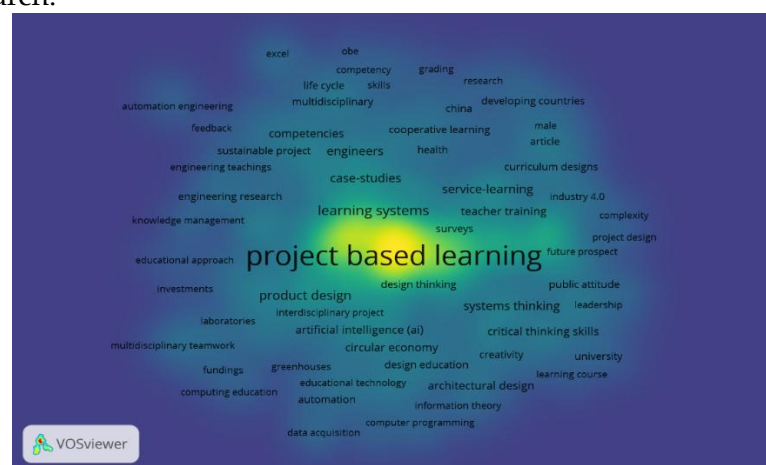


Figure 5. Visualization of the Integration of PjBL and ESD in Education

The density visualization reveals that the distribution of keyword intensity is represented through color gradients, reflecting both the frequency of occurrence and the strength of relationships among topics within the research network. Brighter areas indicate

high-frequency keywords such as project-based learning, sustainable development, planning, student, and problem-based learning, highlighting the dominance of research focused on the development and implementation of project-based learning integrated with sustainability principles and student-centered approaches. In contrast, darker regions, which include keywords like problem solving, critical thinking skills, cooperative learning, and interdisciplinary, suggest that 21st-century skills and interdisciplinary approaches remain less emphasized in existing studies. This pattern indicates significant opportunities for future research, particularly in strengthening critical thinking and problem-solving skills, promoting collaborative learning practices, and integrating multidisciplinary approaches to enhance the quality and innovation of PjBL and ESD-based learning.

The fifth finding, based on the analysis of Scopus subject area distribution, indicates that research on PjBL and ESD encompasses multiple disciplines with varying levels of contribution. The results identify dominant fields while also highlighting the supporting roles of other disciplines in enriching the research landscape. This pattern suggests that the study of PjBL and ESD extends beyond a single domain and reflects a broad, interconnected knowledge base. Overall, the integration of PjBL and ESD has evolved into a multidisciplinary field that bridges education, environmental studies, technology, and the social sciences

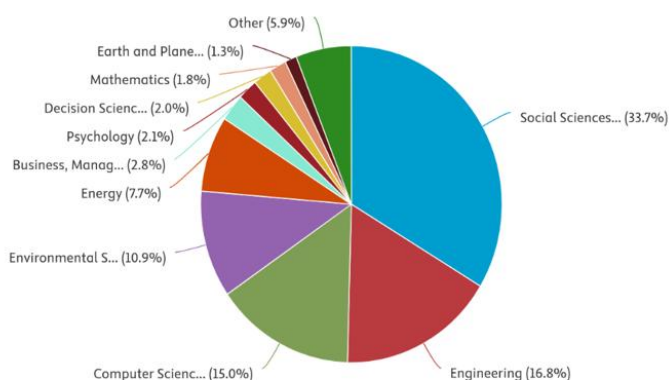


Figure 6. Distribution of Research Fields on the Integration of PjBL and ESD in Education

Research on PjBL and ESD is largely dominated by social sciences 33.7%, highlighting a focus on pedagogy, policy, and student-centered learning, with support from engineering 16.8% and computer science 15.0% indicating technological integration. Contributions from environmental sciences 10.9% and energy 7.7% further emphasize sustainability as a key context. However, fields such as business, psychology, decision science, mathematics, and earth sciences remain underrepresented, suggesting limited integration of managerial, behavioral, and analytical perspectives. Overall, these findings point to the need for a stronger multidisciplinary approach to enhance future research quality and scope.

The sixth finding in this study presents the results of a bibliometric analysis examining the contributions of different countries to scientific publications on the integration of PjBL and ESD. This analysis aims to identify countries that play a dominant role in advancing research in this field during the 2010-2025 period. The results provide an overview of the distribution of publication productivity across countries and highlight the level of participation of each country in the development of research on the integration of PjBL and ESD.

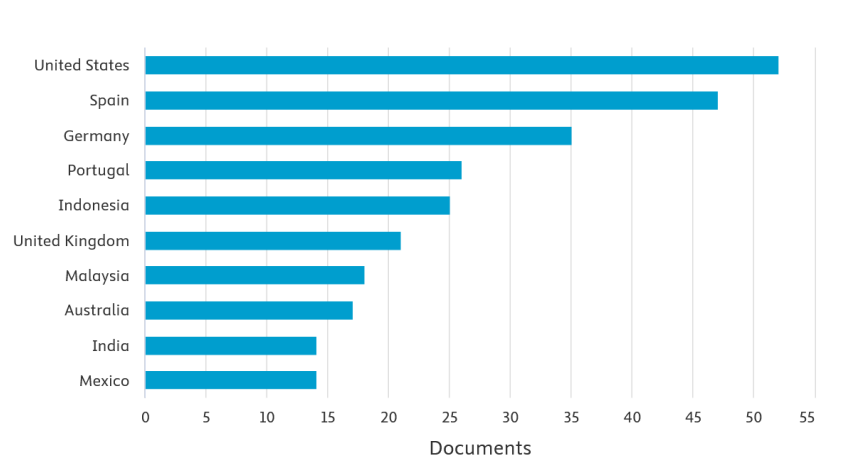


Figure 7. Distribution of Country Publications on the Integration of PjBL and ESD

Based on the distribution of publications by country, the United States ranks first with 52 documents, followed by Spain 47 and Germany 35, highlighting the strong dominance of developed countries in PjBL and ESD research. Notable contributions also come from Portugal 26, Indonesia 25 and the United Kingdom 21, indicating active involvement across both European and Asian regions. Meanwhile, Malaysia 18, Australia 17, as well as Mexico and India 14, demonstrate a moderate level of contribution. Overall, these findings reflect an imbalance in global research output, emphasizing the need to strengthen international collaboration and enhance research capacity in developing countries to achieve a more balanced distribution of publications.

The seventh finding indicates a growing trend in integrating PjBL and ESD to develop 21st-century skills. This integration combines project-based and sustainability approaches to enhance key competencies. Overall, it reflects a shift toward more holistic and contextual learning.

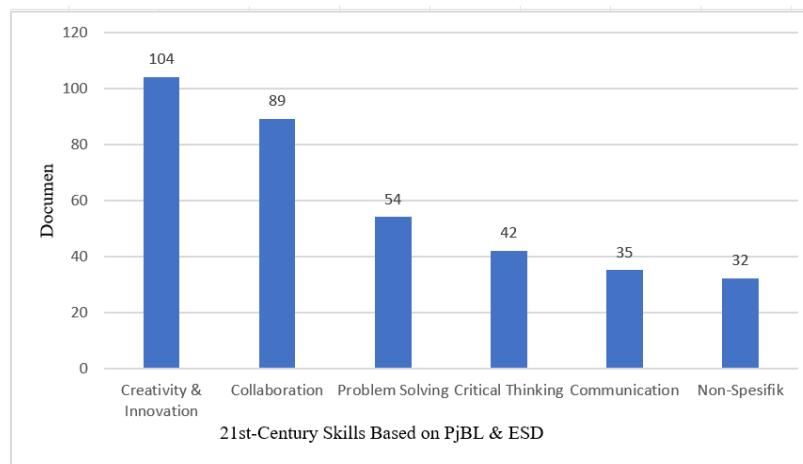


Figure 8. Distribution of the Development of 21st-Century Skills Articles Based on PjBL and ESD

Based on the third finding, the distribution of publications on 21st-century skills based on PjBL and ESD reflects the integration of both approaches in developing competencies aligned with global demands. The synergy between PjBL and ESD indicates a research direction that connects project-based learning with sustainability values in a more comprehensive manner. This integration also promotes the development of skills that extend beyond cognitive aspects to include social awareness and environmental responsibility.

through contextual learning. Overall, these findings suggest a shift toward more comprehensive, collaborative, and problem-solving-oriented learning approaches.

The eighth finding shows that the quartile distribution of PjBL–ESD journals (2010–2025) varies across Q1–Q4 and non-quartile categories. This indicates that research is published at different journal levels with varying visibility and quality. Overall, it reflects the academic standards and global recognition of PjBL–ESD research.

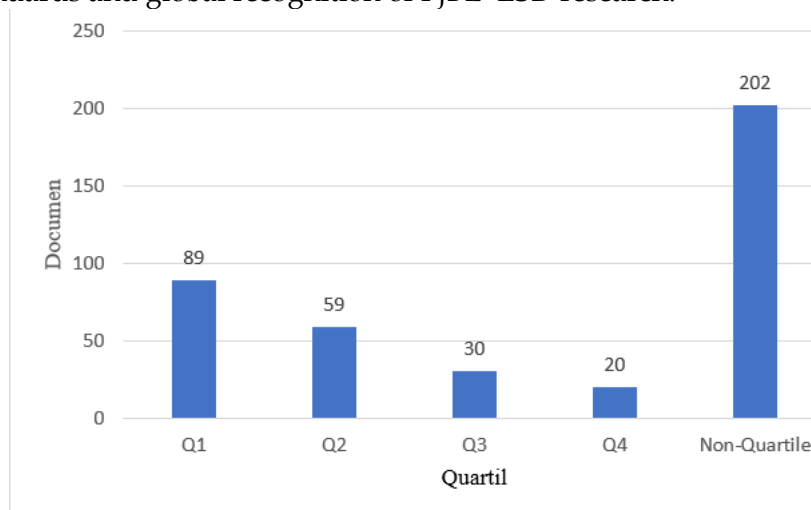


Figure 9.Journal Quartile Distribution of PjBL–ESD Publications (2010–2025)

Based on the quartile distribution of PjBL–ESD journal publications from 2010 to 2025, most publications are still dominated by the non-quartile category, which has the highest number compared to other quartiles. In Scopus-indexed journals, the largest contribution comes from Q1, followed by Q2, Q3, and Q4, showing a decreasing trend. Although the presence of publications in Q1 and Q2 reflects an improvement in research quality, the dominance of non-quartile publications indicates challenges in publishing in reputable journals. Therefore, efforts to enhance research quality and more effective publication strategies are needed to increase the proportion of publications in high-quartile journals

Discussion

The analysis of publication trends shows a shift in research on the integration of PjBL and ESD toward learning approaches that are more responsive to global issues and sustainability (Youssfi & BenFilali, 2026), which were initially still exploratory in nature (Scharenberg et al., 2021). The significant increase after 2020 reflects the growing urgency of sustainable education and the need to strengthen 21st-century skills through innovative approaches (Oktaviana et al., 2026). The sharp rise in 2025 confirms the effectiveness of integrating PjBL and ESD in developing contextual and collaborative learning (Desyta et al., 2026; Supriyanto et al., 2025). This is also supported by the study conducted by Vilmala et al. (2025), which shows that the combination of both approaches can enhance students' critical thinking, collaboration, and sustainability awareness.

The network visualization analysis shows that PjBL and ESD research is grouped into several clusters that reflect the strengthening of higher-order thinking skills such as critical thinking and computational thinking within a sustainability context (Rahmayanti et al., 2021). Active and collaborative learning approaches highlight the effectiveness of PjBL in enhancing student engagement as well as communication and collaboration skills (Nurhamudin et al., 2025), supported by systematic curriculum design (Widiyaningsih et al., 2026). The integration of technologies such as the internet of things indicates a shift toward more innovative digital learning (Yarmi et al., 2026). Overall, the implementation of ESD-based PjBL, particularly in

physics education, has strong potential to improve 21st-century skills and scientific literacy through sustainability-related projects (Desyta et al., 2026).

The overlay visualization shows that PjBL-ESD research has shifted from basic pedagogical foundations toward more complex, innovative, and technology-based approaches. Early studies focused on learning experience and project design (Qohar et al., 2026), followed by the integration of sustainability and higher-order thinking skills (Henita et al., 2025), and more recently by digital technologies such as AI and IoT (Yarmi et al., 2026). In line with the study by Todorova & Kostadinova (2025), this evolution enhances 21st-century skills and supports the development of contextual, data-driven physics learning.

The density visualization analysis indicates that research on the integration of PjBL and ESD is still dominated by key themes related to project-based learning and sustainability, as reflected by the high intensity of keywords such as project-based learning, sustainable development, and problem-based learning (Yarmi et al., 2026). This finding is consistent with the study by Gara et al., (2025), which confirms that PjBL is effective in enhancing student engagement while linking learning to real-world contexts and sustainability issues. The dominance of these themes indicates that the integration of PjBL and ESD has become a primary approach in modern education, emphasizing active and meaningful learning. Overall, this condition suggests that research is increasingly directed toward the development of contextual and sustainability-oriented instructional design.

The subject area distribution shows that the dominance of social sciences in PjBL and ESD research highlights a strong focus on pedagogy, educational policy, and student-centered learning (Howell, 2021). Contributions from engineering and computer science indicate the growing importance of technological integration in innovative project-based learning (Anguera et al., 2024), while environmental sciences and energy emphasize sustainability as a central context. However, fields such as business and management, psychology, decision science, mathematics, and earth and planetary sciences remain less represented, suggesting that managerial, behavioral, and quantitative perspectives are not yet fully integrated. Consistent with Thian et al., (2026), this condition highlights the need to strengthen multidisciplinary research to broaden perspectives, improve learning quality, and support innovation in addressing global challenges.

The distribution of publication contributions by country indicates the dominance of the United States, Spain, and Germany, reflecting strong research ecosystems in developed countries supported by solid policies, funding, and academic collaboration (Hallinger, 2020). This high level of contribution is driven not only by the quantity of publications but also by the consistent development of pedagogical innovations such as PjBL within the ESD context. On the other hand, the increasing contributions from developing countries such as Indonesia and Malaysia show a positive trend, although they still face a gap compared to developed countries (Song & Peng, 2019). This condition highlights the importance of strengthening international collaboration, improving access to research funding, and enhancing policy support to achieve a more balanced distribution of publications.

The dominance of critical thinking skills in PjBL highlights a strong emphasis on developing higher-order thinking abilities, as noted by Dwi & Manalu, (2026) although problem-solving skills remain relatively underrepresented. In the ESD approach, creativity and innovation emerge as the most prominent competencies, supported by Fitriyah et al., (2026), who emphasize the importance of creative, collaborative, and problem-solving skills in sustainability contexts. The integration of PjBL and ESD reflects a trend toward a more holistic, contextual, and problem-oriented development of 21st-century skills (Desyta et al., 2026). However, the limited number of studies in physics education, along with findings from Maghfiroh et al., (2026) indicates the need to strengthen interdisciplinary research to optimize the integration of these approaches more comprehensively.

The distribution of PjBL–ESD publications (2010–2025) is dominated by non-quartile journals, although Q1 and Q2 still indicate higher research quality (Veretennik & Yudkevich, 2023). This pattern suggests that while some studies have met international standards, the overall quality of publications remains uneven. The prevalence of non-quartile outputs also points to challenges such as limited manuscript quality, restricted access to global publication networks, and less effective publication strategies, as highlighted by McKay, (2024) Therefore, strengthening researchers' capacity through improved methodology, expanded international collaboration, and more strategic publishing efforts is essential to increase the share of publications in high-impact journals.

CONCLUSION

The findings indicate that publications on the integration of PjBL and ESD have experienced rapid growth, particularly after 2020, reflecting increasing attention to sustainability-oriented learning. Network analysis reveals the formation of several interconnected clusters, including higher-order thinking skills, collaboration, curriculum development, and technological integration. These results confirm that the research is evolving in a multidisciplinary manner and is increasingly oriented toward contextual learning. Overlay visualization further shows a shift from basic pedagogical approaches toward more complex integration of sustainability and technology. Meanwhile, density visualization highlights the dominance of topics such as PjBL, sustainable development, and problem-based learning within the research landscape. In terms of subject areas, the research is predominantly dominated by the social sciences, although contributions from other fields are gradually increasing. Country-level analysis indicates the dominance of developed countries, with growing participation from developing nations despite existing disparities. Additionally, the prevalence of publications in non-quartile journals suggests the need to improve methodological rigor and publication strategies to increase representation in high-impact journals.

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