

Identifying Gaps and Contributions of Project-Based Learning in Vocational Education and STEM Fields: A Comprehensive Bibliometric Analysis

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ABSTRACT

This bibliometric analysis elucidates the evolution and impacts of Project-Based Learning (PBL) within vocational education, emphasizing its relevance in translating career goals and addressing educational gaps, particularly from 1993 to 2023. Analyzing 555 Scopus-indexed documents, this study utilized advanced bibliometric tools to uncover PBL's growing appeal and its innovative pedagogical integration into design thinking, challenge-based education, and multidisciplinary approaches. Our findings highlight PBL's significant outcomes, including its role in bolstering STEM curricula and fostering critical skill development, thus bridging the gap between theoretical knowledge and practical application essential for the workforce. Despite the documented benefits, our analysis also identifies substantial gaps in research, particularly the scarcity of longitudinal studies on PBL's long-term effectiveness and its comparative efficacy against traditional pedagogies within diverse educational contexts. The study underscores PBL's utility in vocational education as a transformative approach, aligning with dynamic career expectations and the requirements of the knowledge economy. By offering a detailed thematic evolution and pinpointing influential contributions, this research serves as a strategic guide for educators and policymakers, advocating for informed, future-ready educational strategies that embrace experiential learning to meet the evolving needs of students and the labor market.

Keywords: Vocational education, project-based learning, Bibliometric analysis, Skill based learning, Problem solving, Critical thinking.

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Received: 10-06-2023;

Revised: 12-03-2024;

Accepted: 23-12-2024.

INTRODUCTION

Vocational education, commonly known as Career and Technical Education (CTE), is a vital element in the global educational landscape. It serves as a bridge between the theoretical knowledge offered by traditional academic pathways and the practical skills demanded by various industries.^[1] By focusing on hands-on training, vocational education equips individuals with the competencies required to navigate and succeed in sectors like technology, healthcare, and trades, directly addressing the skills gap in the labor market.^[2] The significance of vocational education extends beyond individual career advancement; it's a key driver for economic development, innovation, and overall societal advancement.^[3] However, vocational education is not static; it evolves with the shifting contours of economic demands and technological advancements. The advent of a knowledge-based economy and rapid technological changes have escalated the need

for a workforce that is not only technically skilled but also adept in problem-solving, adaptability, and creativity.^[4] Consequently, traditional methods of vocational training, which primarily emphasized rote learning and direct instruction, have been found wanting.^[5] This inadequacy has catalyzed a pedagogical shift towards more innovative and effective teaching and learning strategies, among which Project-Based Learning (PBL) has been prominent.^[6]

PBL is a dynamic, student-centered instructional model that emphasizes learning through active exploration of real-world challenges and problems.^[7] This method aligns perfectly with the ethos of vocational education, which is anchored in 'learning by doing.' It enriches the educational experience by allowing students to engage deeply with the subject matter, thus fostering a thorough understanding of underlying principles and their practical applications.^[8] John Dewey's philosophy of experiential education, which underscores the importance of learning through experience, provides the foundational theoretical framework for PBL.^[9] The approach is designed to cultivate essential skills such as critical thinking, collaboration, and self-directed learning, which are crucial in today's job market.^[10-13] The existing literature on PBL in vocational education is rich with evidence



DOI: 10.5530/jscires.20250763

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of its benefits, including enhanced skill acquisition, increased student engagement, and improved job readiness. Studies have documented its effectiveness in fostering critical thinking, adaptability, and other soft skills sought by employers.^[14-16]

Despite the extensive research on Project-Based Learning (PBL) in vocational education, there remain significant gaps in our understanding of its long-term effectiveness and adaptability across diverse educational contexts. Most existing studies offer insights into the immediate impacts of PBL, such as enhanced student engagement and skill acquisition, but there's a notable lack of longitudinal research examining the sustained effects on students' career trajectories and job performance.^[17-19] Additionally, while the benefits of PBL are well-documented, there's a paucity of comparative studies that assess the efficacy of PBL against other pedagogical approaches within vocational education. Literature also tends to focus on specific geographical or institutional contexts, leaving a gap in understanding how PBL can be effectively implemented and scaled in diverse educational systems and cultural settings. Moreover, there's a need for more comprehensive studies on the challenges and barriers to implementing PBL, particularly in resource-constrained environments, and how these can be overcome. These gaps highlight the need for more diversified and extensive research to fully comprehend and harness the potential of PBL in vocational education.

Bibliometric analysis is a research methodology that applies statistical methods to written publications, such as books and journal articles, to provide a comprehensive overview of the academic impact and progression within a specific field.^[20,21] This approach is particularly apt for investigating Project-Based Learning (PBL) in vocational education because it allows for the quantification and visualization of data, revealing trends, the prominence of themes, and patterns of authorship and collaboration.^[22,23] By choosing this method, researchers can objectively assess the extent of scholarly interest in PBL, track its evolution over time, and determine the influence of various researchers and institutions on the topic. It provides a meta-analysis of the existing research, which is essential for identifying the most impactful studies, understanding the structure of academic networks, and determining the direction of future research efforts. In the context of vocational education, where industry and pedagogical practices rapidly evolve, bibliometric analysis offers a rigorous means to gauge the field's responsiveness to these changes and the pervasiveness of PBL as a teaching strategy.

This type of analysis is crucial for several reasons:

Trend Analysis

It can identify whether there has been a quantifiable increase in the volume of research dedicated to PBL in vocational education, which is indicative of growing interest and investment in the field.

Contributor Identification**

It can pinpoint key contributors, including authors, institutions, and countries, thereby providing a map of where significant research is being produced and where potential collaborations might be fostered.

Thematic Exploration

It can extract and analyze prevalent themes and discussions within the literature, revealing the core focus areas of PBL research and identifying emerging trends that could guide future researches and practice.

Impact Assessment

It can evaluate the influence of specific studies and authors based on citation analysis, helping to identify seminal works and thought leaders in the field.

In this context, the present study seeks to address three critical research questions through bibliometric analysis: First, how has the research on PBL in vocational education evolved in terms of publication patterns and growth? Second, who are the main contributors to this body of research, and what has been their impact? Lastly, what are the prevailing themes within the PBL literature, and how have they developed over time? To answer these questions, the study will undertake a comprehensive analysis of articles, conference papers, and other relevant publications on PBL in vocational education. The anticipated outcomes of the study include a detailed understanding of the global research landscape of PBL, identification of influential research and researchers, and an overview of the thematic structure of the field. This information will be invaluable for researchers, educators, and policymakers as they seek

METHODOLOGY

A bibliometric analysis was carried out to examine the volume and characteristics of published work pertaining to Project-Based Learning (PBL) in vocational education. This approach enabled the formation of a comprehensive representation of publications in this specific domain by assessing and scrutinizing the bibliographic data embedded within these publications.

Research design

The research methodology for this study mainly involved the selection of suitable bibliographic databases, formulation of search criteria, and choice of software tools for analysis. The Scopus database was chosen as the primary source for data collection for several reasons. It offered relevant and reliable information on publications, owing to its multidisciplinary bibliographic data and policy of emphasizing peer-review. Scopus is often the database of choice for bibliometric analysis due to its vast coverage, high-quality data, advanced search capabilities, unique author and affiliation identifiers, comprehensive citation

data, and various analytical tools.^[24] It covers a broad spectrum of disciplines, including science, technology, medicine, social sciences, arts, and humanities, ensuring a comprehensive bibliometric analysis.^[25] The data credibility is backed by rigorous quality checks, and advanced search options allow for precise data retrieval.^[26] Unique identifiers help in reducing author and affiliation ambiguities, a common issue in bibliometric studies, while its detailed citation data allows for in-depth analysis of citation patterns and trends. Furthermore, Scopus offers several tools for data analysis, including citation overview, bench marking, and analytics, all of which are invaluable in bibliometric studies. The search criteria were established in alignment with the research objectives and questions. A suite of keywords focusing on Project-Based Learning (PBL) in vocational education were identified and used. Boolean operators such as “OR” and “AND” were used to facilitate an expansive yet targeted search, capturing as many pertinent results as possible while eliminating unrelated data. There were no specific temporal restrictions placed on the publication date to provide a comprehensive overview of the evolution of PBL in vocational education. The research scope included all subject areas, recognizing the multidisciplinary and cross-disciplinary nature of the study. Only peer-reviewed journal articles were considered for inclusion to ensure the reliability of the results, and only publications in English were selected for analysis.

The software tools Biblioshiny and VOSviewer were employed for this study due to their robust features designed for bibliometric analysis. Biblioshiny, a user interface of the Bibliometrix package in R, allows for comprehensive data extraction, processing, and analysis of bibliographic data.^[27] It provides functionalities for data importing from various sources, including Scopus, and helps in creating datasets for longitudinal analysis, producing several bibliometric measures and visualizations. On the other hand, VOSviewer is a powerful tool used for creating maps based on network data and is particularly effective for visualizing bibliometric networks.^[28] These networks may include journals, researchers, or individual papers, providing a visual representation of their relationships. Together, these tools offer a comprehensive approach to bibliometric analysis, combining advanced analytical capabilities with powerful visualization tools.

Collection of data

The complete search strategy, which has been formulated based on the criteria established during the research design phase, is encapsulated in Table 1.

A total of 3397 publications were initially obtained based on the established search keywords. However, 2656 of these were excluded due to non-compliance with the research design criteria, including the type of document, the publication's source type, and the language used. The remaining 741 publications underwent manual review for eligibility by scrutinizing the titles

and abstracts of each article. This step resulted in an additional 186 publications being omitted, as they were determined to be unrelated to the project-based learning. After eliminating duplicates, unidentified bibliometrics, and irrelevant articles, the final data set comprised 555 publications. These were exported in the “CSV” (Comma-Separated Value) format from the Scopus database, ready for the subsequent bibliometric analysis. The entire data collection process adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology,^[29] which utilizes a four-phase flow diagram to track the selection process systematically. This process is illustrated in Figure 1. A descriptive analysis was performed to assess the volume of publications, overall developmental trajectory, citation count, and productivity in the field of Project-Based Learning (PBL) in vocational education. In addition, the influence of authors, articles, journals, and countries, as well as an examination of author keywords and topical trends, were also considered. To further understand the landscape, a network analysis was conducted using data visualization and scientific mapping techniques. This included analyzing the co-occurrence of keywords to identify common themes, performing cluster analysis to group similar studies together, and conducting thematic evolution analysis to track the progression of research themes over time.

RESULTS

Annual publication distribution pattern

This data provides a comprehensive overview of the bibliometric analysis of Project-Based Learning (PBL) in vocational education conducted from 1993 to 2023. The data source comprises 133 various resources, including journals and books, from which 555 documents were considered. The annual growth rate of these publications stands at 6.44%, indicating a consistent increase in the volume of literature on this subject over the 30-year period. The average age of a document within this dataset is 7.31 years, and the average number of citations per document is 17.96. This

Table 1: Search strategy.

Type	Criteria
Database	Scopus
Search string	TITLE-ABS-KEY ((“project-based learning” OR “PBL”) AND (“vocational education” OR “vocational training” OR “vocational technical education” OR “engineering education”))
Subject field	All
Timespan	All
Source	Journal
Document	Article
Language	English
Date of search	07 June 2023

latter figure suggests a substantial level of scholarly engagement with these works, underscoring their relevance and influence in the field. A total of 18,175 references were found within the documents collected. In terms of document contents, 2,544 “Keywords Plus” and 1,302 “Author’s Keywords” were identified. These terms provide insight into the recurring and central themes explored in literature. Regarding authorship, 1,636 different authors contributed to the corpus of documents, with 73 authors producing single-authored documents. The degree of collaboration is further reflected by the fact that the average number of co-authors per document is 3.27. The data also reveals a significant degree of international collaboration, with 17.3% of the documents having international co-authorship. This focus on articles signifies a preference for the depth and rigor typically

associated with this type of scholarly output in the analysis. The main information about data is listed in Table 2.

The dataset shown in Figure 2 depicts the annual progression of published articles on Project-Based Learning (PBL) in vocational education from 1993 to 2023. From 1993 to 2002, the field saw minimal activity, with no more than 3 articles published per year. This suggests that PBL in vocational education was not a widely researched topic during this period. A significant increase in the number of articles occurred in 2003, with 13 articles published that year. The level of publication activity remained relatively stable through 2007, with a slight dip in 2007. From 2008 onward, the field began to witness a steady rise in publication frequency. This upward trend indicates a growing interest and

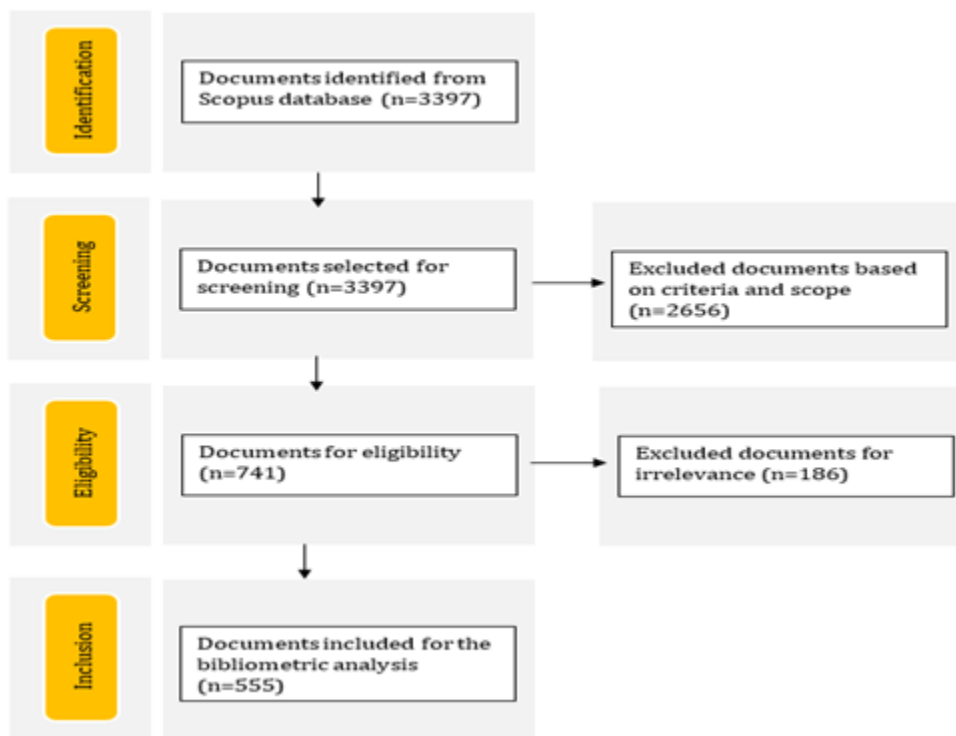


Figure 1: PRISMA Methodology for documents selection.

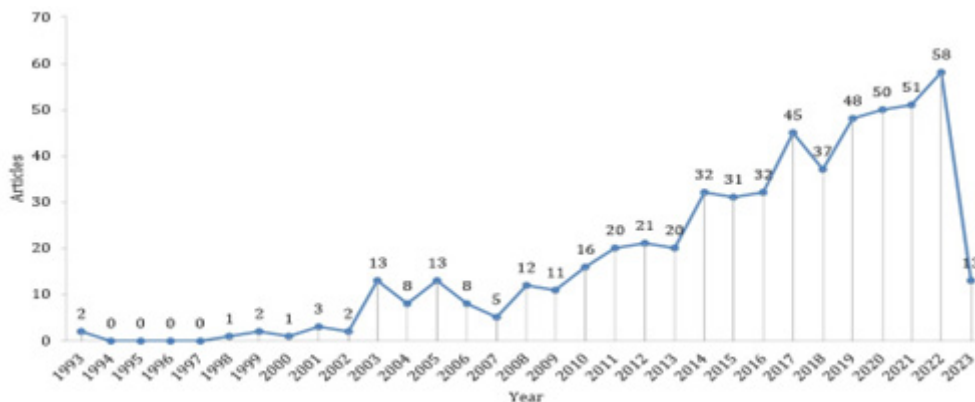


Figure 2: Annual production of articles from 1984 to 2023.

Table 2: Main information about data.

Timespan	1993:2023
Sources (Journals)	133
Documents (Article)	555
Annual growth rate %	6.44
Document average age	7.31
Average citations per doc	17.96
Keywords plus (ID)	2544
References	18175
Author's keywords (DE)	1302
Authors	1636
Authors of single-authored docs	73
Single-authored docs	84
Co-Authors per doc	3.27
International co-authorships %	17.3

recognition of PBL in vocational education among scholars. A more considerable surge is observed from 2014 onward, with the number of annual publications frequently surpassing 30. In 2017, the number of articles jumped to 45, representing a substantial increase in research output compared to previous years. The growth continued, reaching its peak in 2022 with 58 articles published that year. The year 2023, although not yet complete at the time of data collection, already had 13 articles, suggesting the field's continued dynamism. Overall, the data signifies a growth trend in PBL in vocational education research, highlighting its rising importance as a research area. The increasing number of publications also suggests that PBL in vocational education has been receiving escalating scholarly attention and validation, implying its recognized value in enhancing vocational education outcomes.

Main contributors in terms of journals, authors, countries, and documents

The top 10 journals in terms of the number of publications are listed in Table 3.

The "International Journal of Engineering Education" leads the pack, having published 99 articles on the topic. This suggests that the integration of PBL in vocational education is a major focus in the realm of engineering education. The "European Journal of Engineering Education" is the second most prolific, contributing 73 articles. This indicates significant interest and ongoing research in PBL within the context of European vocational engineering education. "IEEE Transactions on Education" ranks third with 63 articles. As IEEE is a renowned international professional organization dedicated to the advancement of technology, this journal's active engagement with PBL in vocational education underlines the perceived importance of this teaching methodology in technological and engineering disciplines. "Journal of

Engineering Education Transformations" and "Computer Applications in Engineering Education" have also significantly contributed to the body of knowledge with 20 and 19 articles, respectively, highlighting the relevance of PBL to these specific aspects of engineering education. The "International Journal of Electrical Engineering and Education", "Advances in Engineering Education", and "Journal of Professional Issues in Engineering Education and Practice" each have published between 11 and 15 articles on PBL in vocational education, further illustrating the topic's relevance across various engineering disciplines. International Journal of Technology and Design Education, with 10 articles, highlights the application and efficacy of PBL in the spheres of technology and design education. The data reflects a strong interest in PBL within the field of engineering education, underlining the method's potential for enhancing learning outcomes in vocational and technical education settings.

The distribution of authors productivity concerning the frequency of published articles on Project-Based Learning (PBL) in vocational education has been analyzed using Lotka's Law. This law postulates that the number of authors making contributions is about $1/n^2$ of those making one contribution. According to the data observed, the bulk of the contributions (92.7%) come from authors who have written a single document, indicating a large pool of individual contributors to the field. This aligns with Lotka's Law, which predicts that most authors will contribute only once. In this context, authors who have contributed twice to the corpus make up 5.4% of the total authorship, those who have contributed three times make up 1.2%, and those who have made four contributions are 0.4%. The number continues to decrease with the rise in the number of contributions, with one author having written five documents and three authors having written seven documents, each representing 0.1% and 0.2% of total authorship respectively. Notably, one author has contributed twelve times, a significant outlier in the distribution. Overall, the distribution generally aligns with Lotka's Law, demonstrating that in the field of PBL in vocational education, there are many authors who contribute once or twice, and fewer authors who contribute more frequently. The data shown in Table 4 and Figure 3 presents a geographical analysis of the scientific production rate and the distribution of publication frequency across different countries provides a valuable perspective on global engagement with this field of study. The United States leads the scientific production, contributing 371 articles to the corpus of PBL literature, indicating a high degree of interest and research activity in this field within the country. Spain, the second-most productive country, has contributed 297 articles, exhibiting substantial research efforts in this domain in the European context. China, with 124 articles, ranks third, showing significant interest in PBL within the Asian academic landscape. Portugal and Australia are also noteworthy contributors, with 85 and 77 articles respectively, reflecting their active research environments around PBL in vocational education. Denmark and India have

each contributed 69 articles, showcasing their engagements with PBL. Meanwhile, Malaysia and the United Kingdom each produced 67 articles, demonstrating their commitment to exploring and enhancing PBL in vocational settings. Lastly, Brazil, with 60 articles, contributes to the research corpus from a South American perspective. Overall, the data underscores a global interest in PBL in vocational education, with the United States and Spain leading in terms of research output, followed by a range of countries from different regions worldwide.

The citation analysis conducted in the study highlights the five most influential papers as shown in Table 5. The most cited paper, authored by De Graaf *et al.*^[30] titled “Characteristics of problem-based learning”, has accrued 579 citations, reflecting its profound influence on the understanding of problem-based learning methodologies. Another seminal work is “Implementing the Project-Based Learning approach in an academic engineering course” by Frank M *et al.*^[31] which has garnered 296 citations, highlighting its practical application in engineering education. The third influential paper, “Problem-Oriented and Project-Based Learning (POPBL) as an innovative learning strategy for sustainable development in engineering education” by M. Lehmann *et al.*^[32] has 272 citations, demonstrating its impact in introducing sustainable pedagogical strategies. Tseng *et al.*^[33] work “Attitudes towards Science, Technology, Engineering and Mathematics (STEM) in a Project-Based Learning (PBL) environment” has received 235 citations, indicating its importance in shaping attitudes towards STEM education. Lastly, “PBL

and CDIO: complementary models for engineering education development” by Kristina Edstrom.^[34] has amassed 180 citations, emphasizing the synergies between two effective pedagogical models, PBL and Conceive-Design-Implement-Operate (CDIO), for enriching engineering education.

Frequently discussed themes and evolving trends

This segment delves into the prominent themes in the research on Project-Based Learning (PBL) in vocational education and their evolution over time by examining the keywords and thematic progression. An analysis of keyword co-occurrence serves as an effective method for representing the structure of scholarly knowledge, pinpointing hot topics, and identifying patterns within a specialized domain. The extraction, mapping, and clustering of terms from keywords allows for the clear demarcation of research themes. As depicted in Figure 4, the map consists of circles and lines with each circle acting as a node that corresponds to an author’s keyword. The size of the circle is indicative of the frequency of occurrence—larger circles represent keywords that appear more often in the literature. The connecting line between two nodes signifies the degree of relationship between two keywords. The line’s thickness demonstrates the frequency of keyword co-occurrence, while the distance between two nodes represents the strength of topic similarity. Each circle’s color corresponds to the specific cluster of the keyword to which the node belongs. For this section of the study, the co-occurrence of author keywords served as the analytical unit to examine the research themes in PBL. A minimum co-occurrence threshold was set at four, after which the co-occurrence of a total of 69 author keywords were visualized and subsequently divided into distinct categories. Cluster 1 aggregates a set of keywords that encapsulate the concepts of “project-based learning”, “engineering education”, “experiential learning”, “education”, “curriculum”, “skills”, and “STEM”. This cluster demonstrates a significant thematic emphasis on the integration of project-based and experiential learning methods within the curriculum of engineering and STEM education, with a particular focus on skill development.

Table 3: Most relevant sources.

Rank	Journal	Number of articles
1	International Journal of Engineering Education.	99
2	European Journal of Engineering Education.	73
3	IEEE Transactions on Education.	63
4	Journal of Engineering Education Transformations.	20
5	Computer Applications in Engineering Education.	19
6	International Journal of Electrical Engineering and Education.	15
7	Advances in Engineering Education.	14
8	Journal of Professional Issues in Engineering Education and Practice.	14
9	International Journal of Mechanical Engineering Education.	11
10	International Journal of Technology and Design Education.	10

Table 4: Scientific production based on country.

Country	Frequency
USA	371
Spain	297
China	124
Portugal	85
Australia	77
Denmark	69
India	69
Malaysia	67
UK	67
Brazil	60

Table 5: Top five most globally cited documents.

First author	Year	Title	Total citations	TC per year
De Graaf	2003	Characteristics of problem-based learning.	579	27.57
Frank M	2003	Implementing the Project-Based Learning approach in an academic engineering course.	296	14.10
M. Lehmann	2008	Problem-Oriented and Project-Based Learning (POPBL) as an innovative learning strategy for Sustainable development in engineering education	272	17
Tseng, KH	2013	Attitudes towards Science, Technology, Engineering, and Mathematics (STEM) in a Project-Based Learning (PBL) environment.	235	21.36
Kristina Edstrom	2014	PBL and CDIO: complementary models for Engineering education development	180	18

To illustrate the evolution of Project-Based Learning (PBL), a thematic evolution analysis was performed. The analysis used Callon centrality (theme importance) and Callon density (theme development) to categorize themes into four typologies as shown in Figure 5. Themes in the upper-right quadrant are significant and well-developed,

while those in the lower-right quadrant are important but focus on specific cross-cutting topics. Themes in the lower-left quadrant are marginal and less developed, while those in the upper-left quadrant, though less important, are well-developed in a specific domain. Design thinking, challenge-based education, and multidisciplinary education are the emerging themes. These contemporary themes underline the evolving nature of project-based learning, emphasizing innovative problem-solving approaches, an increased focus on real-world issues, and the intersection of various fields of study. The prominence of these topics suggests a shift towards more holistic, interdisciplinary, and application-based learning approaches in educational research and practice.

DISCUSSION

The discussion section of this bibliometric analysis illuminates the burgeoning interest and substantive evolution in the research landscape of Project-Based Learning (PBL) within vocational education, spotlighting an annual growth rate of publications at 6.44% over three decades. This trend not only signifies the escalating scholarly engagement with PBL but also mirrors the shifting pedagogical paradigms in response to the evolving demands of the global labor market. The analysis delineates a movement from traditional, didactic teaching methods towards more innovative, student-centered pedagogical frameworks like design thinking, challenge-based education, and interdisciplinary learning. Such methodologies emphasize active engagement, critical thinking, collaboration, and real-world problem-solving, skills deemed essential for the contemporary workforce. The shift

toward Project-Based Learning (PBL) in vocational education represents a significant pedagogical evolution, deeply rooted in several influential educational theories that emphasize active, engaged, and contextual learning. This paradigmatic transition is not just a trend but a response to the changing demands of the global workforce and the need for education systems to produce graduates who are not only knowledgeable but also adept in critical 21st-century skills such as problem-solving, collaboration, and adaptability.

Theoretical underpinnings

At the heart of this pedagogical shift is the Constructivist Learning Theory,^[35] which asserts that learners construct knowledge through experiences and reflections on those experiences. This theory lays the foundation for PBL by advocating that learning is most impactful when students are actively involved in meaningful tasks that require them to navigate and solve real-world problems. PBL, with its emphasis on engaging students in projects that simulate real-life challenges, aligns perfectly with this constructivist approach, ensuring that learning transcends the acquisition of theoretical knowledge to include the development of practical skills and critical thinking abilities. Complementing the constructivist perspective is the Theory of Situated Cognition,^[36] which posits that knowledge and learning are intricately linked to the context in which they occur. This theory reinforces the value of PBL in vocational education, where the seamless integration of theoretical knowledge and practical application is crucial. By sitting within authentic contexts, PBL not only enhances comprehension and retention but also better prepares students for the complexities and nuances of workplace environments. The experiential nature of PBL ensures that students gain hands-on experience, fostering a deeper understanding of subject matter and enhancing their ability to apply knowledge in practical settings. Furthermore, the 21st Century Skills framework underscores the imperative for education systems to cultivate skills such as creativity, critical thinking, collaboration, and communication.

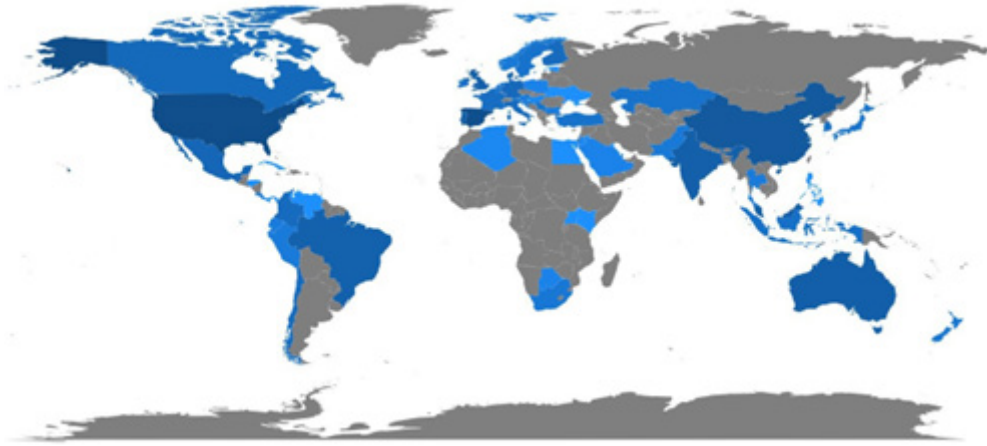


Figure 3: Plot of Scientific production based on country.

PBL caters to this need by incorporating interdisciplinary projects and teamwork into the curriculum, thereby creating a learning environment that encourages the development of these essential competencies. This approach prepares students to thrive in a dynamic and interconnected world, where the ability to navigate complex problems and work collaboratively across disciplines is paramount. The Theory of Interdisciplinary Integration^[37] highlights the necessity of bridging diverse fields of knowledge to tackle today's multifaceted challenges. The increasing adoption of multidisciplinary approaches within PBL in vocational education, as evidenced by our analysis, illustrates the practical application of this theory. It signifies a move towards educational experiences that transcend traditional disciplinary boundaries, thereby equipping students with a versatile and comprehensive skill set that is adaptable to various contexts and challenges.

Global Trends and Contributions

The bibliometric analysis conducted in this study reveals not only the quantitative growth of PBL research in vocational education but also qualitative shifts towards more innovative and integrated pedagogical models. This global trend is reflective of an educational paradigm shift towards methods that are more aligned with the demands of the modern workplace, which values problem-solving, adaptability, and interdisciplinary collaboration. Countries leading in PBL research, such as the United States and Spain, have shown a significant commitment to developing and implementing PBL strategies within their vocational education systems. This commitment suggests a recognition of the value of PBL in enhancing educational outcomes and preparing students for the workforce. The international collaboration patterns identified in our analysis further highlight the importance of cross-border educational initiatives in sharing best practices and fostering innovation in vocational education strategies. The thematic evolution of PBL research indicates a growing interest in integrating innovative pedagogical frameworks like design thinking and challenge-based education. These frameworks

resonate with the theoretical underpinnings of PBL, emphasizing the importance of engaging learners in problem-solving and creative thinking processes. The focus on interdisciplinary and multidisciplinary approaches further underscores the recognition of the complex nature of real-world problems, which often require solutions that draw upon diverse fields of knowledge. The expanding body of research on PBL in vocational education, as evidenced by our bibliometric analysis, underscores a significant pedagogical shift towards more engaged, experiential, and context-based learning environments. This shift, grounded in solid educational theories and aligned with global educational trends, points towards an evolving educational paradigm. One that not only addresses the immediate skills needs of the labor market but also prepares students to navigate the complexities of a rapidly changing world. As such, the insights derived from this analysis serve as a valuable resource for educators, policymakers, and researchers, guiding the future development of vocational education to better meet the demands of the 21st-century workforce.

Implications for Practice and Policy

The insights gleaned from this analysis bear significant implications for educators, policymakers, and curriculum developers. For educators, the findings underscore the importance of embracing PBL and related methodologies to create more engaging, relevant, and effective learning experiences. Curriculum developers are called upon to integrate these pedagogical models into vocational education programs, ensuring that students not only acquire technical skills but also develop the soft skills necessary for the modern workplace. For policymakers, the international collaboration pattern highlights the potential for cross-border initiatives in vocational education. Sharing best practices and resources can facilitate a more unified and effective approach to incorporating PBL across different educational systems and cultural contexts. While this analysis provides a comprehensive overview of PBL in vocational education, it also illuminates

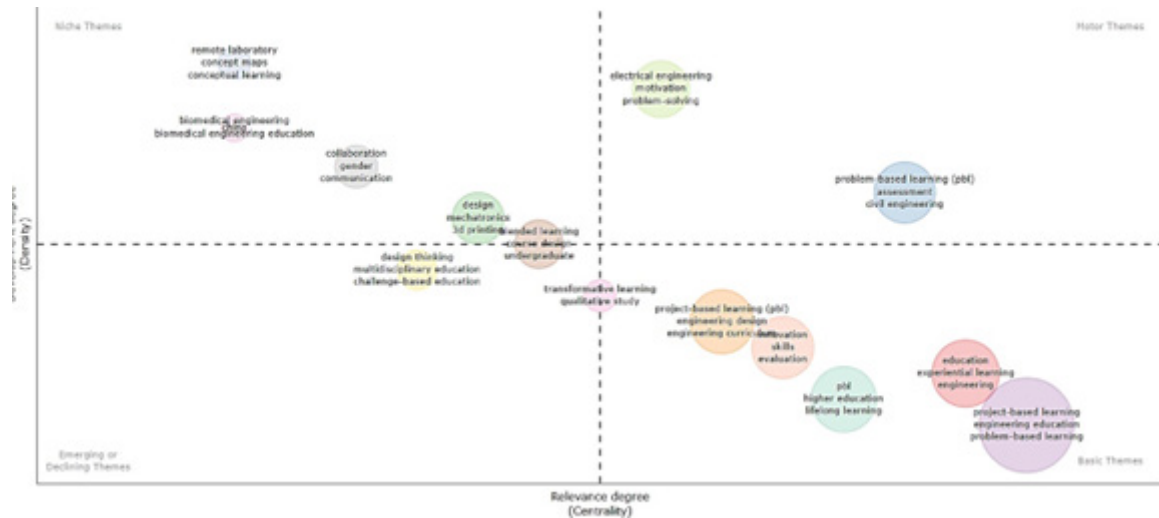


Figure 5: A thematic evolution analysis of Project-Based Learning (PBL).

and even evaluation processes, ensuring that students engage in learning activities that mirror real-world challenges and requirements. In contrast, countries that are less effective in harnessing the potential of PBL often face challenges such as limited industry engagement, lack of resources, and insufficient teacher training in PBL methodologies. These challenges hinder the ability of educational institutions to provide students with meaningful project-based experiences that are closely tied to industry needs. Without the active participation of industry partners, PBL initiatives may fail to capture the dynamic nature of the labor market, rendering the learning experience less relevant and impactful for students' career trajectories. Furthermore, the absence of a supportive policy framework and adequate funding can exacerbate these issues, limiting the scope and quality of PBL implementation. The disparities in PBL effectiveness highlight a critical need for countries lagging to learn from the experiences of their more successful counterparts. For instance, establishing stronger connections between vocational schools and local industries can create more opportunities for students to engage in projects that are directly relevant to their future careers. Such partnerships can also facilitate knowledge exchange, whereby educators can gain insights into emerging industry trends and skills requirements, while industry professionals can contribute to curriculum development and provide mentorship to students. Moreover, investing in teacher training is essential to ensure that educators are equipped with the skills and knowledge to design and facilitate effective PBL experiences. Professional development programs that focus on PBL methodologies can empower teachers to create engaging, real-world projects and assess student learning in meaningful ways. Additionally, policy initiatives that promote industry involvement in vocational education and provide financial support for PBL initiatives can create a more conducive environment for the adoption and scaling of PBL strategies. In summary, the gaps between countries in the effectiveness of PBL implementation offer valuable lessons for those looking to enhance their vocational education systems.

By fostering closer industry-education partnerships, investing in teacher training, and supporting policy and funding mechanisms that promote PBL, lagging countries can bridge the gap and leverage PBL as a powerful tool for preparing students for success in the modern workforce. This approach not only benefits individual learners but also contributes to the broader economic and societal development by ensuring a skilled, adaptable, and future-ready workforce.

Limitations of the study

While this bibliometric analysis provides a comprehensive exploration of the trajectory and impact of Project-Based Learning (PBL) in vocational education, particularly emphasizing its contributions to STEM fields and its role in addressing educational and career-related challenges, it is essential to acknowledge the study's limitations for a balanced assessment of the findings. These limitations not only offer scope for critical reflection but also pave the way for future research directions that can further enrich our understanding of PBL's potential and application. Firstly, the study's reliance on Scopus-indexed documents in English introduces a language bias, potentially overlooking significant research published in other languages or within less accessible databases. This limitation could mean that the analysis may not fully capture the global scope of PBL research, especially contributions from non-English speaking regions where PBL might be implemented in unique and contextually relevant ways. As educational paradigms and pedagogical innovations vary widely across different cultural and educational systems, a more inclusive research methodology that encompasses a broader linguistic and geographic spectrum could reveal additional insights and diversify our understanding of PBL's global impact. Moreover, the bibliometric methodology, while powerful for mapping trends, authorship, and citation networks, may not fully capture the qualitative nuances of research quality or the practical impact of PBL implementations.

Bibliometric analysis excels in highlighting the most cited and potentially influential papers, but citation counts alone do not always equate to practical relevance or pedagogical effectiveness. Consequently, there's a need for complementary research approaches, such as meta-analyses or qualitative case studies, that can delve deeper into the pedagogical contexts, learner experiences, and long-term impacts of PBL on vocational outcomes. Another significant limitation is the study's snapshot nature, which, despite covering three decades of research, may not adequately address the dynamic and evolving nature of PBL and its application in vocational education. The pace of technological advancement and the shifting demands of the labor market require continuous adaptation and innovation in educational strategies. As such, the study's findings, while indicative of trends up to 2023, may not fully anticipate future developments in PBL pedagogy, emerging technological tools that could enhance PBL implementation, or evolving skills demands of the workforce. The study also identifies a gap in longitudinal research on the long-term effects of PBL on students' career trajectories and job performance, pointing to a need for future studies that track vocational outcomes over time. This limitation underscores the challenge of measuring the sustained impact of educational interventions in a rapidly changing world. Longitudinal studies, potentially incorporating mixed methods to combine quantitative outcomes with qualitative insights, could offer a more comprehensive understanding of how PBL influences career readiness and success.

Furthermore, the analysis suggests a paucity of comparative studies assessing the efficacy of PBL against other pedagogical approaches within vocational education. This gap highlights an opportunity for future research to systematically evaluate PBL's effectiveness, providing educators and policymakers with evidence-based guidance on the most impactful teaching and learning strategies for vocational training. Additionally, the thematic analysis, while uncovering emerging trends and areas of focus within PBL research, may not fully account for the practical challenges of implementing PBL in diverse educational settings. Factors such as institutional support, teacher training, resource availability, and curriculum alignment play critical roles in the successful adoption of PBL. Research that specifically addresses these implementation challenges, particularly in resource-constrained environments, could provide valuable insights for practitioners looking to adopt or adapt PBL methodologies. While this bibliometric analysis sheds light on the significant growth and thematic evolution of PBL research in vocational education, acknowledging its limitations invites a more nuanced understanding and encourages further exploration. Future research that addresses these limitations can enhance our comprehension of PBL's effectiveness, inform practice and policy, and ultimately contribute to the development of a robust, skill-oriented education system that aligns with the needs of students and the global labour market.

Recommendations: Bridging Gaps in Project-Based Learning (PBL) in Vocational Education and STEM Fields

The findings of this comprehensive bibliometric analysis spotlight significant insights into the evolution, contributions, and persisting gaps within the realm of Project-Based Learning (PBL) in Vocational Education and STEM fields. These insights not only illuminate the pathway for academic inquiry but also delineate actionable strategies for policymakers and educational practitioners. Herein, we propose recommendations aimed at leveraging the strengths and addressing the limitations of PBL, focusing on innovative teaching methods and competency indicators as vital components for enhancing vocational and STEM education.

Innovative teaching methods

Integration of Digital Technologies

To bridge the identified research gaps, especially in adapting PBL to diverse educational contexts, there's a pressing need for integrating digital technologies into PBL methodologies. Policymakers and educational institutions should prioritize the development and dissemination of digital tools that facilitate interactive, project-based learning experiences. These technologies can range from virtual reality (VR) simulations that provide immersive learning environments to online platforms that enable collaborative projects across geographical boundaries.

Training and Professional Development

The effectiveness of PBL hinges on the competency of educators to design, implement, and assess project-based activities. It's imperative that policymakers allocate resources towards comprehensive professional development programs for teachers. These programs should not only cover the fundamentals of PBL but also emphasize innovative teaching strategies, assessment methodologies, and the integration of digital tools into the curriculum.

Curriculum Co-creation with Industry

Addressing the gap between theoretical knowledge and practical application requires a curriculum developed in collaboration with industry stakeholders. This partnership ensures that the educational content is aligned with current industry standards and future job market needs. By involving industry professionals in curriculum design and project creation, educational institutions can provide students with real-world problem-solving experiences, thereby enhancing job readiness.

Competency indicators

Development of competency frameworks

To systematically assess the impact of PBL on student outcomes, there's a need for well-defined competency frameworks that

align with the requirements of the modern workforce. These frameworks should detail the specific skills and knowledge that students are expected to acquire through PBL, including technical proficiencies, critical thinking, problem-solving, and collaborative skills. Competency indicators within these frameworks can serve as benchmarks for curriculum development, instructional strategies, and assessment methods.

Longitudinal studies on competency development: Policymakers and research institutions should commission longitudinal studies to track the development of these competencies among students engaged in PBL. These studies would provide valuable data on the long-term efficacy of PBL in vocational and STEM education, informing future educational policies and practices.

Policy support for PBL implementation

The success of PBL in vocational and STEM fields depends on robust policy support, including funding, infrastructure development, and the establishment of industry-education partnerships. Policies should encourage the sharing of best practices and innovations in PBL across institutions and borders. Furthermore, incentives for schools and educators that successfully implement PBL and demonstrate improvement in competency development among students can catalyse the broader adoption of PBL methodologies.

Addressing the gaps in Project-Based Learning within Vocational Education and STEM fields necessitates a concerted effort from policymakers, educators, industry partners, and researchers. By focusing on innovative teaching methodologies and the development of clear competency indicators, the potential of PBL to enhance vocational and STEM education can be fully realized. These recommendations aim to guide strategic actions that foster an education system equipped to meet the dynamic needs of students and the global labour market, ensuring that vocational education continues to be a cornerstone of economic development and societal progress.

CONCLUSION

This bibliometric analysis spanned three decades of scholarly activity and charted the intellectual contours of PBL within the vocational education landscape. The study's findings suggest a significant shift towards innovative, experience-based education models, with PBL emerging as a pivotal pedagogical approach in vocational training. The increasing volume of literature, growing citation rates, and the expanding international collaboration are indicative of the global recognition of PBL's effectiveness. This surge in interest reflects an educational paradigm shift towards methods that are more aligned with the demands of modern workplaces, emphasizing problem-solving, adaptability, and interdisciplinary collaboration. The implications of these findings are multifaceted. For practitioners, the evolution towards pedagogies like design thinking and challenge-based

education reveals an opportunity to reimagine curriculum design, focusing on active, student-centered learning experiences that simulate real-world challenges. For policymakers, the global trends highlighted by this analysis underscore the potential benefits of international cooperation in developing educational strategies and policies that support the widespread adoption and adaptation of PBL methodologies. Moreover, the significance of these findings extends to educational researchers. The analysis identifies key contributors and the most influential works, establishing a knowledge base from which future studies can be developed. It serves as a call to probe deeper into the identified emerging themes, such as the integration of PBL with STEM education, which has the potential to revolutionize vocational training to produce graduates with the skills and acumen needed for the 21st-century workforce. However, studying is not without limitations. The dependence on Scopus-indexed documents in English may have introduced a language bias, potentially overlooking relevant research published in other languages or within less accessible databases. Additionally, the bibliometric tools used, while sophisticated, cannot fully articulate the nuances of research quality or the practical impact of the analyzed studies. These limitations underscore the need for caution in the interpretation of the findings and suggest avenues for future research.

Recommendations for future research include the expansion of the dataset to incorporate multilingual publications and grey literature, which may reveal additional insights into PBL's application in vocational education. Longitudinal studies are also recommended to assess the enduring impacts of PBL on vocational outcomes and employability. Furthermore, comparative studies between different pedagogical approaches could provide a more detailed understanding of PBL's effectiveness relative to other educational strategies. For practitioners, this study recommends the development of collaborative networks that facilitate the exchange of PBL best practices and innovations across international boundaries. Additionally, there is a call for the integration of emerging trends identified in this study, such as multidisciplinary approaches and design thinking, into the educational curriculum.

In closing, this bibliometric analysis serves as a foundational piece, charting the past and present of PBL in vocational education and paving the way for its future development. The study's insights should be leveraged to foster a robust, skill-oriented education system that is responsive to the evolving needs of students and the global labor market, ensuring that vocational education remains a vital, dynamic force for personal and societal advancement.

ABBREVIATIONS

PBL: Project-Based Learning; **STEM:** Science, Technology, Engineering, and Mathematics; **CTE:** Career and Technical Education; **COVID-19:** Coronavirus Disease 2019; **Scopus:**

Scientific Journal Database; **WOS**: Web of Science; **Q1/Q2**: Quartile Rankings; **ID**: Identifier; **DE**: Descriptive Entry; **TC**: Total Citations; **SJ**: SCImago Journal; **UAE**: United Arab Emirates; **GCC**: Gulf Cooperation Council; **IUM**: International Islamic University Malaysia; **INCEIF**: International Centre for Education in Islamic Finance; **KODISA**: Korea Distribution Science Association; **ISRA**: International Shariah Research Academy; **IPAG**: Institut de Préparation à l'Administration et à la Gestion; **LeBow**: LeBow College of Business; **PRISMA**: Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

CONFLICT OF INTEREST

The author declares that there is no conflict of interest.

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Cite this article: Ibrahim A. Identifying Gaps and Contributions of Project-Based Learning in Vocational Education and STEM Fields: A Comprehensive Bibliometric Analysis. *J Scientometric Res*. 2025;14(1):86-98.