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Mapping the global research on project-based learning: a bibliometric and network analysis (2014–2024)

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Background: Project-based learning (PjBL) is a widely adopted educational approach known for fostering critical skills such as collaboration, problem-solving, and self-regulated learning. Despite its global implementation across various educational levels and disciplines, there has been limited comprehensive analysis of global research trends in PjBL.

Objective: This study maps the global research on PjBL.

Methods: We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, bibliometrics, and network analyses to analyze 2,273 peer-reviewed articles indexed in the Web of Science Core Collection and published between January 2014 and August 2024.

Results: Our findings show a significant increase in PjBL research over time, with an 800% growth in publications since 2014. The most frequent keywords are engineering education, higher education, and STEM, and the main research areas are Education and Educational Research, Engineering, and Computer Science. The United States of America, Spain, and China are the leading countries in publications. Additionally, the network analysis shows strong collaborations, particularly between organizations in the USA and Asia.

Conclusion: This study offers a broad understanding of the global research landscape on PjBL, delivering key insights for future studies and promoting collaborative research among organizations worldwide.

KEYWORDS

project-based learning, scientific publications, PRISMA, bibliometrics, network analysis

1 Introduction

Project-based learning (PjBL) is a student-centered instructional approach that aligns with constructivist principles, emphasizing learning as an active, context-specific process driven by real-world problems (Cocco, 2006; Kokotsaki et al., 2016; Rodriguez-Sanchez et al., 2024; Zhang and Ma, 2023). Originating from the constructivist theory, particularly social constructivism (Handrianto and Rahman, 2018; Rodriguez-Sanchez et al., 2024), PjBL promotes knowledge construction through inquiry, collaboration, and the production of tangible outcomes, often culminating in an artifact or presentation (Blumenfeld et al., 1991; Miller et al., 2021; Thomas, 2000). Unlike traditional teacher-led education, which relies on passive knowledge acquisition, PjBL engages students in problem-solving tasks that require them to formulate questions, conduct investigations,

analyze data, and communicate findings (Blumenfeld et al., 1991; Chen and Yang, 2019). Overall, PjBL projects usually entail five criteria, which are centrality to the curriculum, questions that drive students, constructive investigations, student autonomy, and realism (Thomas, 2000).

PjBL is often considered more effective than traditional methods for fostering critical 21st-century skills, including critical thinking, communication, collaboration, and self-regulated learning (Bell, 2010; Chu et al., 2017a; Kokotsaki et al., 2016; Maros et al., 2023). Research has demonstrated that PjBL improves students' academic achievement (Boaler, 1998; Chen and Yang, 2019), promotes engagement (Bender, 2012), and supports deeper understanding and retention of knowledge compared to more traditional instructional methods (Blumenfeld et al., 1991; Thomas, 2000; Wijnia et al., 2024).

PjBL shares common features with other inquiry-based and collaborative learning approaches such as Problem-based learning (PBL; Chu et al., 2017a). Briefly, PBL is an instructional approach that uses real-world or simulated problems as the starting point for learning, emphasizing student-driven inquiry, critical thinking, and collaborative problem-solving (de Andrade Gomes et al., 2024; Lopes et al., 2024). However, while PBL usually begins with a well-defined problem, PjBL often starts with guiding questions that frame the problem. Overall, compared to PBL, PjBL is considered to provide students with greater autonomy in directing their learning (Wijnia et al., 2024) and to engage students with real-world cases instead of scenarios or cases that can be more abstract (Rodriguez-Sanchez et al., 2024).

Adopted across various educational levels and subjects, the research related to PjBL varies greatly. Studies explore contexts ranging from, e.g., studies on teaching methodologies of Korean culture class (Kim, 2024), Arabic writing skills in differentiated learning (Salsabila and Baroroh, 2024), development of competencies for undergraduate nursing students (Lee et al., 2024), and environmental awareness of secondary school students (López and Palacios, 2024). This diversity illustrates the need to map the global research landscape on PjBL to identify emerging trends, key areas of study, and the institutional networks that drive this research. Hence, this study aims to map the global research related to PjBL and answer the following questions: How has research on PjBL developed over the last 10 years? What are the key topics and research areas within this field? Which organizations lead in this research, and which are their collaborative networks?

We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), bibliometrics, and network analyses to assess 2,273 peer-reviewed articles indexed in the Web of Science Core Collection (WoS) published between January 2014 and August 2024. PRISMA is a well-established guideline for conducting and reporting systematic reviews and meta-analyses (Page et al., 2021). Bibliometrics quantitatively analyzes publications, citations, and other bibliographic data, allowing the evaluation of aspects such as topic emergence, trends within a research domain, and the productivity of research organizations. Meanwhile, network analysis focuses on examining interconnected systems or structures, often visualized as networks, and is commonly used to explore collaboration patterns, information flow, and influence within a research field (de Andrade Gomes et al., 2024; Lopes et al., 2024).

TABLE 1 Search strategies carried out in the Web of Science.

Set	Search strategy	Results
#1	TI=("project-based learning" or "PjBL") and Article or Early Access or Review Article (Document Types)	880
#2	AB=("project-based learning" or "PjBL") and Article or Early Access or Review Article (Document Types)	1,749
#3	AK= ("project-based learning" or "PjBL") and Article or Early Access or Review Article (Document Types)	1,513
#4	#1 OR #2 OR #3	2,321
#5	#1 OR #3	1,732
#6	#2 NOT #5	589

*TI (Title), AB (Abstract), AK (Author Keywords).

In recent years, some studies related to PjBL have been published using systematic reviews (Amarathunga et al., 2024; Chiu et al., 2022; Liu et al., 2023), bibliometrics (Amarathunga et al., 2024; Archilla-Segade, 2024; Chiu et al., 2022; Halibas and Do Thi Hoang, 2024), or network analysis (Henderson, 2024; Liang et al., 2024; Liu et al., 2023). Overall, these studies evaluate specific aspects or subjects within PjBL. For example, PjBL in science education (Konu Kadirhanogullari and Ozay Kose, 2023), and scientific production on PjBL related to arts (Archilla-Segade, 2024). None of them, however, combine PRISMA, bibliometrics, and network analysis to perform a comprehensive assessment of global publications on PjBL. Therefore, our study presents a global overview of research on PjBL over the last 10 years, enhancing our understanding of this educational approach, providing valuable insights to guide future studies, and encouraging inter-institutional collaboration among researchers from institutions around the world.

2 Methods

We assessed the global research on PjBL indexed in WoS from 2014-01-01 to 2024-08-29. Only articles, review articles and early access were considered. The search strategies were carried out in the advanced search mode of WoS and are depicted in Table 1.

The field tags TI (Title), AB (Abstract), and AK (Author Keywords) search the titles, abstracts, and author keywords of the records, respectively. The search strategies used the terms "project-based learning" and "PjBL," conducted on August 29, 2024, yielding 2,321 results (Table 1, set #4). These records were exported from WoS in plain text format and imported into the data/text mining software VantagePoint 11.0 (Search Technology, 2018) for data analysis, where co-occurrence matrices for network analysis were also generated. We automatically included 1,728 articles where the descriptors appeared in the titles or author keywords (set #5; four duplicated records were removed before screening). Articles with "project-based learning" or "PjBL" in titles or keywords are likely focused on this educational approach, but abstracts alone provide less certainty. To address this, we randomly screened for eligibility 39.66% (233) of the 588 abstracts from set #6 in Table 1 (one duplicated record was removed before screening), using a 95%

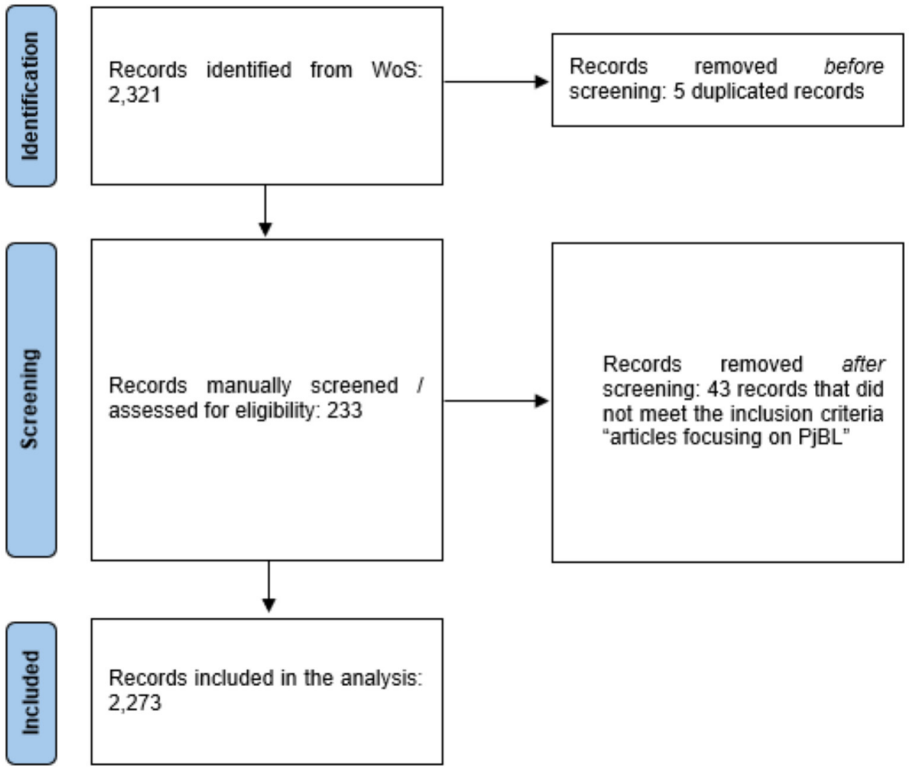

FIGURE 1
PRISMA flowchart.

confidence level. One author (BC) screened the titles and abstracts, excluding 43 articles, with no disagreement after review by a second author (FM). Articles focused on PjBL were included, while those not meeting this criterion were excluded. After screening, 545 records were added to the 1,728 automatically included, resulting in 2,273 records for analysis. The list of included and excluded articles is in the Supplementary material. Figure 1 shows the flow of identification, screening, and inclusion/exclusion of records.

We analyzed publication year, journals, titles, abstracts, author keywords, author affiliations (organizations), countries, Research Area (RA, a subject classification by WoS), times cited in WoS, and cited references. Author keywords and organizations were processed using VantagePoint's list cleanup tool with general matching rules, followed by manual cleaning.

Co-occurrence matrices of author keywords, RAs, countries, and organizations were imported into Gephi 0.10 for network analysis. A co-occurrence matrix is a mathematical representation that depicts how often pairs of items (e.g., keywords, organizations, countries) appear together in a given dataset. Each row and column represents an item, and the values in the matrix indicate the frequency of their co-occurrence. In network analysis, a co-occurrence matrix is used to construct networks where nodes represent the individual items and edges (connections) are formed based on the co-occurrence values (i.e., how often two items appear together). Networks were built and analyzed using degree centrality (DC), weighted degree centrality (WDC), closeness centrality (CC), betweenness centrality (BC), and eigenvector centrality (EC). DC measures the number of connections a node has, while WDC accounts for connection strength. CC evaluates a node's proximity to others, BC identifies nodes on the shortest paths, and EC assesses both a node's connections and the influence of connected nodes (de Andrade Gomes et al., 2024; Lopes et al., 2024; Scott and Carrington, 2014). These centrality metrics are often used in network analysis studies to reveal core characteristics of networks such as the strength of collaboration between organizations and countries, and relationships between different items (e.g., keywords, research areas; de Andrade Gomes et al., 2024; Lopes et al., 2024). We also calculated graph density, a measure of network connectivity ranging from 0 to 1, indicating the ratio between existing and potential edges (Askar et al., 2021).

In the figures presenting frequency and co-occurrence data, the number of items displayed in rankings or networks depends on both the "weight" of each item relative to the total dataset and the clarity of the visualization. The selection of items displayed in the Figures is subjective, as it is based on the authors' assessment of the data. This approach aligns with previous studies and is a common practice in the field (de Andrade Gomes et al., 2024; Lopes et al., 2024). In the networks, node size and color represent WDC, and edge thickness indicates frequency of co-occurrence. The network layout was generated using the Fruchterman-Reingold algorithm (Gephi: http://github.com/gephi/gephi/wiki/Fruchterman-Reingold). All centrality values from Gephi are included in the Supplementary material. Bibliometrics and network analysis cover the period of the search strategy: 2014-01-01 to 2024-08-29. Graphs and figures were created with GraphPad Prism 8, and the 2023 Impact Factors were obtained from Clarivate's

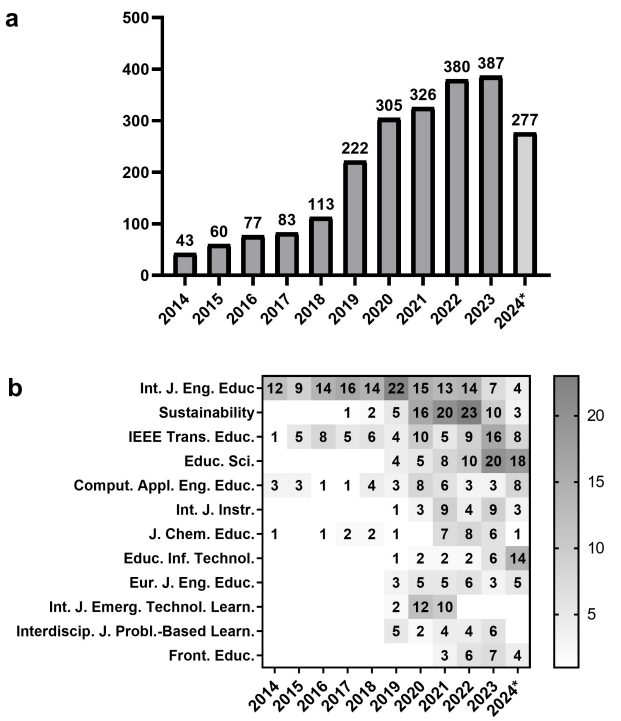

FIGURE 2
Publication and Journals. **(A)** Annual publication during the period. **(B)** Annual publication of the journals with 20 or more articles during the period. Full names of the journals and their 2023 Impact Factors: International Journal of Engineering Education (0.7); Sustainability (3.3); IEEE Transactions on Education (2.1); Education Sciences (2.5); Computer Applications in Engineering Education (2.0); International Journal of Instruction (1.9); Journal of Chemical Education (2.5); Education and Information Technologies (4.8); European Journal of Engineering Education (2.0); International Journal of Emerging Technologies in Learning (N/A); Interdisciplinary Journal of Problem-Based Learning (0.6); Frontiers in Education (1.9). The asterisk in 2024 means that data for 2024 covers the period 2024-01-01 to 2024-08-29.

Journal Citation Reports (http://jcr.clarivate.com/). The average annual growth rate (AAGR) was used to assess the average annual growth of publications and PjBL keywords over the period. It was calculated as AAGR $= \frac{GR_{t=1}+GR_{t=2}+GR_{t=3}+\ldots+GR_{t=n}}{n}$, where n is the number of years and $GR_t = \frac{V_t - V_{t-1}}{V_{t-1}}$. The GR_t is the year growth rate, where t is the current year, V_t is the value for the current year and V_{t-1} is the value in the previous year (Koller et al., 2020; de Andrade Gomes et al., 2024; Lopes et al., 2024; Mota et al., 2022).

3 Results

The annual publications surpassed 100 articles for the first time in 2018, peaking in 2023 with 387 articles, which represents 17.03% of all publications. The increase rate of publications on PjBL between 2014 and 2023 is 800.00%, and the AAGR from 2014 to 2023 is 30.10%. From January to August 2024, the number of articles totaled 71.58% of the previous year (Figure 2A). Eight hundred journals published papers on PjBL during the period. The International Journal of Engineering Education ranks first with 6.16% of all publications, followed by Sustainability (3.52%) and IEEE Transactions on Education (3.39%; Figure 2B). The 2023 Impact Factor (IF) of the journals with 20 or more published papers ranges from 0.6 (Interdisciplinary Journal of Problem-Based Learning) to 4.8 (Education and Information Technologies), with a median of 2.0.

Besides PjBL (occurring in 66.30% of all articles), engineering education, higher education, and STEM (an acronym for science, technology, engineering, and mathematics) were the three most cited author keywords of the analyzed period, comprising respectively 6.99, 6.16, and 5.63% of all publications. PjBL as an author keyword surpassed 100 for the first time in 2019. Between 2014 and 2023, the occurrence of PjBL in author keywords increased by 756.67%, showing an AAGR of 31.27% over the period (Figure 3A). After PjBL, which ranks first in all centrality metrics (DC: 39.0; WDC: 2,578.0; EC: 1.0; CC: 1.0; BC: 0.06066), the most central node of the network of keywords is STEM, which is second in all metrics (DC: 35.0; EC: 0.908597; CC: 0.906977; BC: 0.046137) but WDC (384.0; fourth position). PBL is third in all metrics (DC: 33.0; EC: 0.888689; CC: 0.866667; BC: 0.033656), except for WDC (310.0; fifth). Engineering education and higher education are second and third in WDC, 500.0 and 406.0, respectively. This network comprises 40 nodes and 414 edges and has a graph density of 0.531. This graph density indicates that 53.10% of all viable node-to-node connections are established. The most co-cited keywords were PjBL and engineering education (co-cited 124 times), PjBL and higher education (89), PjBL and STEM (78), and PjBL and PBL (61; Figure 3B).

Assigned to 66.17% of all papers, Education and Educational Research (E&ER) was the most frequent RA related to PjBL, followed by Engineering (21.51%), and Computer Science (8.89%; Figure 4A). In 2023, 68.22, 13.18 and 8.27% of all papers were assigned to these three RAs, respectively (Figure 4A). The network of RAs has 37 nodes, 84 edges, and a graph density of 0.126 (12.60% of all possible connections established). E&ER is the most central node according to all metrics (DC: 20.0; WDC: 1,120.0; CC: 0.717391; BC: 0.387144) but EC (0.968607; second). Engineering is first in EC (1.0) and second in WDC (1,088.0), and Computer Science is second in DC (18.0), CC (0.673469), and BC (0.245298). The most frequently co-assigned RAs were E&ER and Engineering (346), Engineering and Computer Science (83), E&ER and Computer Science (65), and E&ER and Chemistry (29; Figure 4B).

Over the period, the United States of America (USA) led in publications, having published 22.48% of all papers. Comprising 16.94 and 7.87% of all papers, Spain and China rank second and third, respectively. From 2014 to 2017, Indonesia, fourth in the ranking, had no publications on PjBL. Its publications increased over time, and in 2023, 7.75% of all papers were authored by authors affiliated with organizations based in this country (Figure 5A). With 37 nodes, 178 edges, and a graph density of 0.267 (26.70% of possible connections established), the network of countries shows the USA as the most central node considering all centrality metrics (DC: 28.0; WDC:252.0; EC: 1.0; CC: 0.818182; BC: 0. 235783). The USA is followed by Spain (DC: 25.0; WDC: 158.0; EC: 0.867802; CC: 0.765957; BC: 0.200277) and China (DC: 19.0; WDC: 148.0; EC: 0.750264; CC: 0.679245; BC: 0.069253), which are second and third in all metrics, respectively. The most frequent inter-country collaborations were between researchers from the USA and China

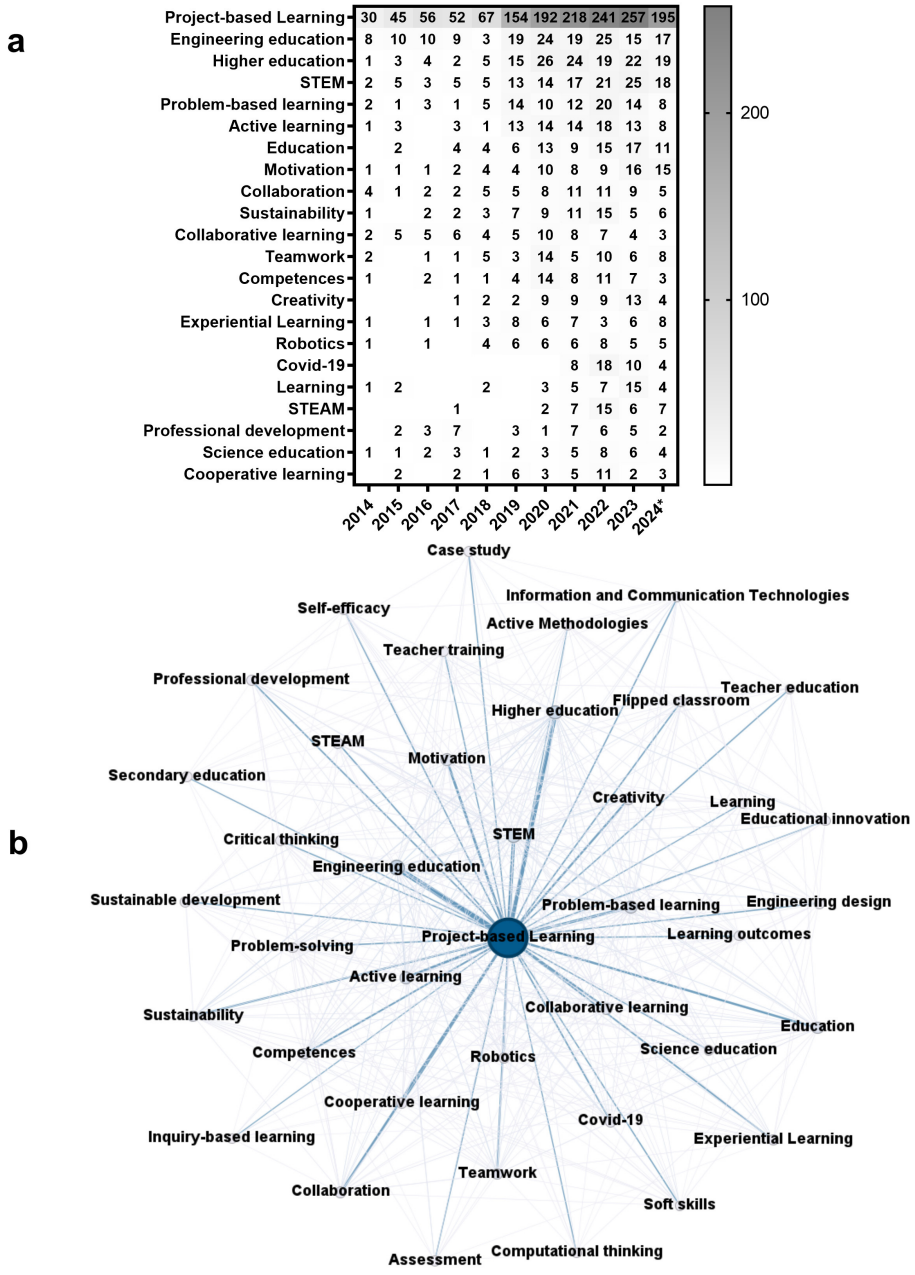

FIGURE 3
Keywords 1. **(A)** Evolution of keywords over time (frequency of 35 or more). **(B)** Network of keywords (frequency of 25 or more). Undirected network comprising 40 nodes and 414 edges. Nodes refer to keywords, and edges refer to the frequency of co-occurrence between keywords. Minimal and maximal values of co-occurrences are 1 and 124. The asterisk in 2024 means that data for 2024 covers the period 2024-01-01 to 2024-08-29.

(18), the USA and Germany (14), the USA and Australia (11), and the USA and South Korea (11; Figure 5B).

Seventeen organizations totaled 15 or more articles in the period. Of the top 15 most productive organizations on PjBL, 29.41% are Spanish and 29.41% are American. The Universidad Politécnica de Madrid (UPM, Spain) leads the ranking with 1.32% of all publications, followed by the Universitat de València (UV, Spain; 1.10%), and the National Taiwan Normal University (NTNU, Taiwan; 1.06%; Figure 6A). The network of organizations comprises 35 nodes and 27 edges and has a graph density of 0.045 (4.50% of possible connections established). Indiana University (IU, USA) leads alone in DC (4.0) and EC (1.0), and the University of California (UC, USA) in BC (0.169935). Michigan State University (MSU, USA) and the University of Hong Kong (HKU, Hong Kong, China) rank first in WDC (14.0), while the highest CC (1.0) is shared by the UPM, Universitas Negeri Malang (UM, Indonesia), and Universitas Negeri Yogyakarta (UNY, Indonesia). The most frequent research collaborations were between researchers from Aalborg University (AAU, Denmark) and Qatar University (QU, Qatar; with five papers published together), the University of Michigan (UM, USA) and Michigan State University (MSU, USA;

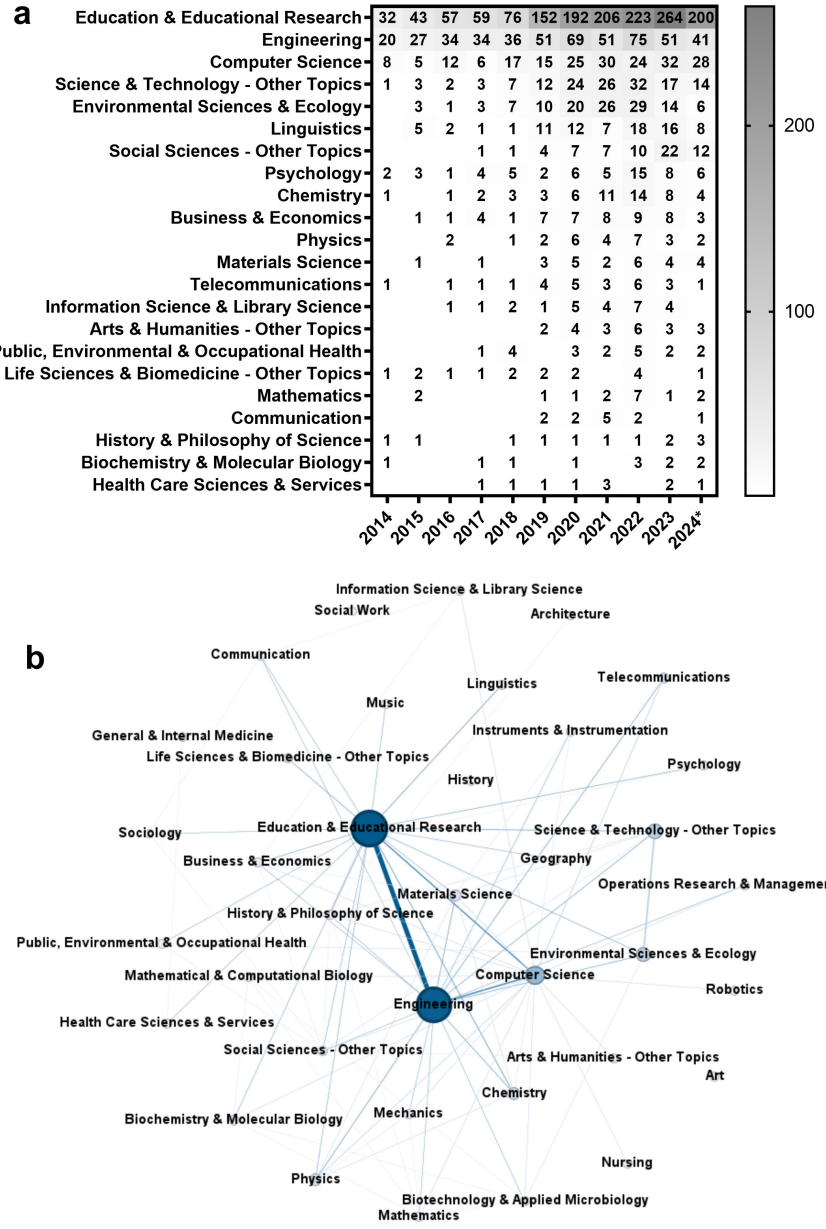

FIGURE 4
Research areas. **(A)** Evolution of RAs over time (frequency of 10 or more). **(B)** Network of RAs (frequency of 5 or more). Undirected network comprising 37 nodes and 84 edges. Nodes refer to RAs, and edges refer to the frequency of co-occurrence between RAs. Minimal and maximal values of co-occurrences are 1 and 346. The asterisk in 2024 means that data for 2024 covers the period 2024-01-01 to 2024-08-29.

4), and HKU and Beijing Normal University (BNU, China; 4; Figure 6B).

As of the data collection date, 14 articles had been cited 82 times or more in WoS. The three most cited were 10.1016/j.compedu.2018.07.004 (330 citations), 10.1016/j.compedu.2016.03.003 (276), and 10.1016/j.ijer.2020.101586 (229; Figure 7A). Among the 40,280 references (with a DOI) cited by the articles in our dataset, 17 received 50 or more citations. The top three were 10.1207/s15326985ep2603&4_8 (265 citations), 10.1080/00098650903505415 (199), and 10.1177/1365480216659733 (185; Figure 7B).

4 Discussion

The results of this study highlight a significant increase in global research on PjBL over the analyzed period, revealing the growing recognition of its educational value. The 800% rise in publications between 2014 and 2023 suggests an expanding interest in student-centered pedagogies that prioritize active learning and problem-solving, key elements of PjBL (Kokotsaki et al., 2016). This trend is further evidenced by the increasing number of studies from disciplines such as STEM, engineering education, and higher education, where hands-on, collaborative learning methods are

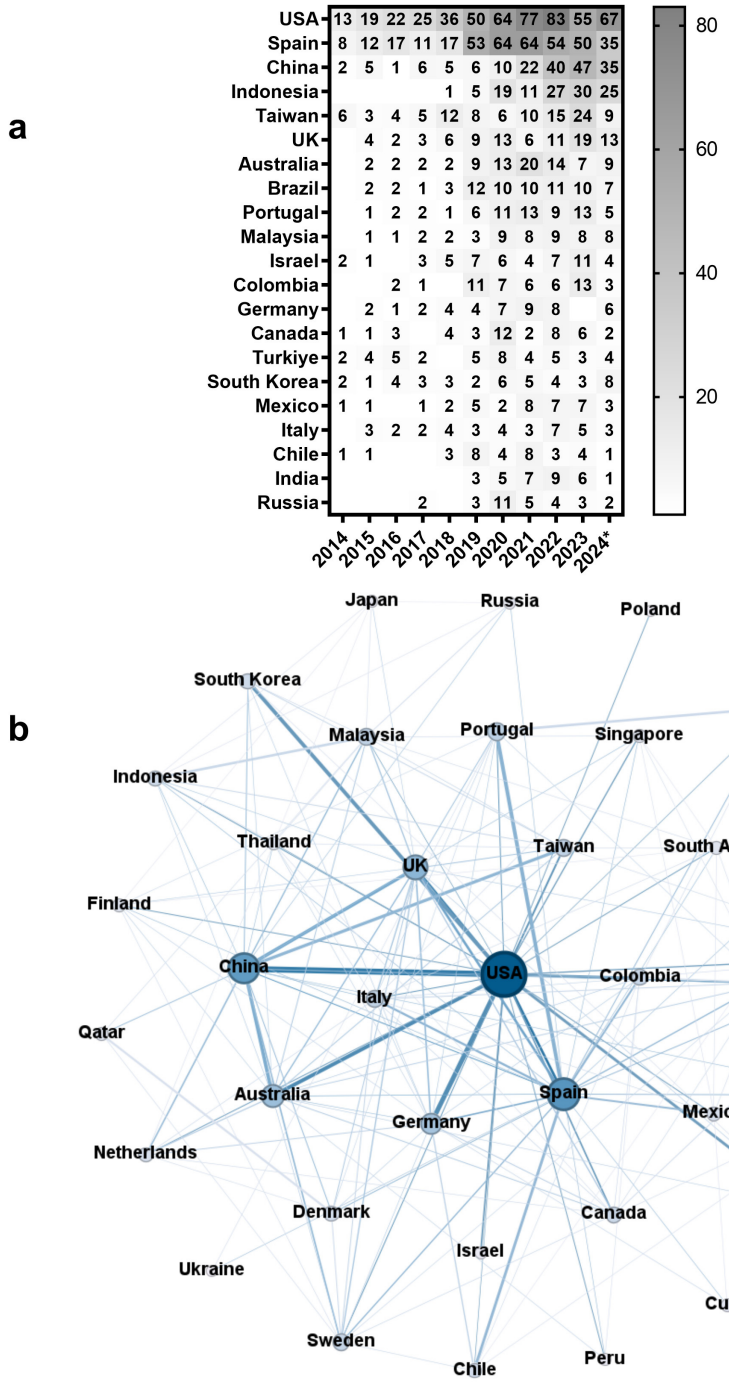

FIGURE 5
Countries. **(A)** Countries' publications over time (frequency of 30 or more). **(B)** Network of Countries (frequency of 15 or more). Undirected network comprising 37 nodes and 178 edges. Nodes refer to countries, and edges refer to the frequency of co-occurrence between countries. Minimal and maximal values of co-occurrences are 1 and 18. The asterisk in 2024 means that data for 2024 covers the period 2024-01-01 to 2024-08-29.

particularly valued (Han et al., 2015; Hanif et al., 2019). The rapid growth in PjBL research aligns with global educational reforms, which have placed greater emphasis on equipping students with critical thinking, creativity, and teamwork skills (Bender, 2012; Chu et al., 2017a).

The prominence of STEM-related keywords and journals, such as the International Journal of Engineering Education and IEEE Transactions on Education, in the PjBL landscape is unsurprising, given that science and engineering education rely heavily on inquiry-based learning to prepare students for real-world challenges (Jungmann, 2019). As illustrated in our keywords network analysis, keywords such as "STEM," "engineering education," and "higher education" are highly central in the PjBL research network. STEM education, in particular, has leveraged PjBL's capacity to foster deeper conceptual understanding through experimentation and project design, allowing students to

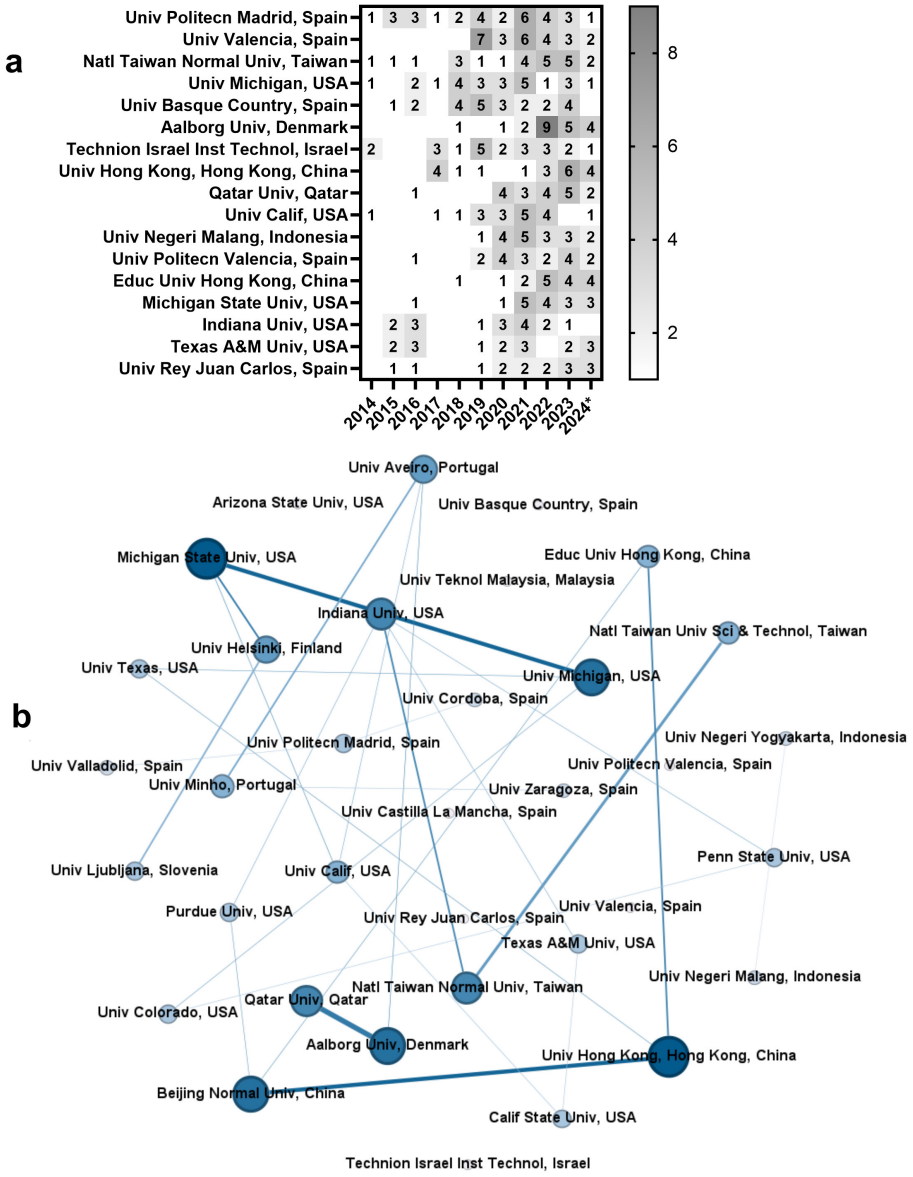

FIGURE 6
Organizations. **(A)** Organizations' publications over time (frequency of 15 or more). **(B)** Network of organizations (frequency of 10 or more). Undirected network comprising 35 nodes and 27 edges. Nodes refer to organizations, and edges refer to the frequency of co-occurrences between organizations. The list of full names and acronyms of the organizations with a frequency of 10 or more is available in the Supplementary material. Minimal and maximal values of co-occurrences are 1 and 5. The asterisk in 2024 means that data for 2024 covers the period 2024-01-01 to 2024-08-29.

apply theoretical knowledge in practical contexts (Mioduser and Betzer, 2008). Engineering education has similarly adopted PjBL to simulate professional environments where students collaborate on complex projects that mirror industry practices (Karim et al., 2020). Overall, the network results reflect a structured and hierarchical network where PjBL research is particularly concentrated in engineering and higher education contexts and is conceptually close to PBL. The RAs analysis adds to this evidence, showing Engineering as the second most common RA besides Education and Educational Research and with a strong interconnection between these fields in the network analysis.

The keyword network's density (0.531) further demonstrates the interconnectedness of research themes within PjBL. This relatively high density suggests that the field is not fragmented but rather characterized by an exchange of ideas across diverse educational domains. The close relationship between PjBL and PBL is particularly noteworthy, as these approaches share common foundations in inquiry-based and collaborative learning (Chu et al., 2017a). PBL typically uses the appropriate problem as the starting point, while in PjBL, guiding questions about the problem often initiate the learning process (Wijnia et al., 2024). Compared to PBL, PjBL often grants students more control over the learning process, with teachers playing a more supportive role (Wijnia et al., 2024). While PBL encourages students to apply knowledge in new situations, it often uses scenarios or cases that may be more abstract compared to the real-world tasks typical of

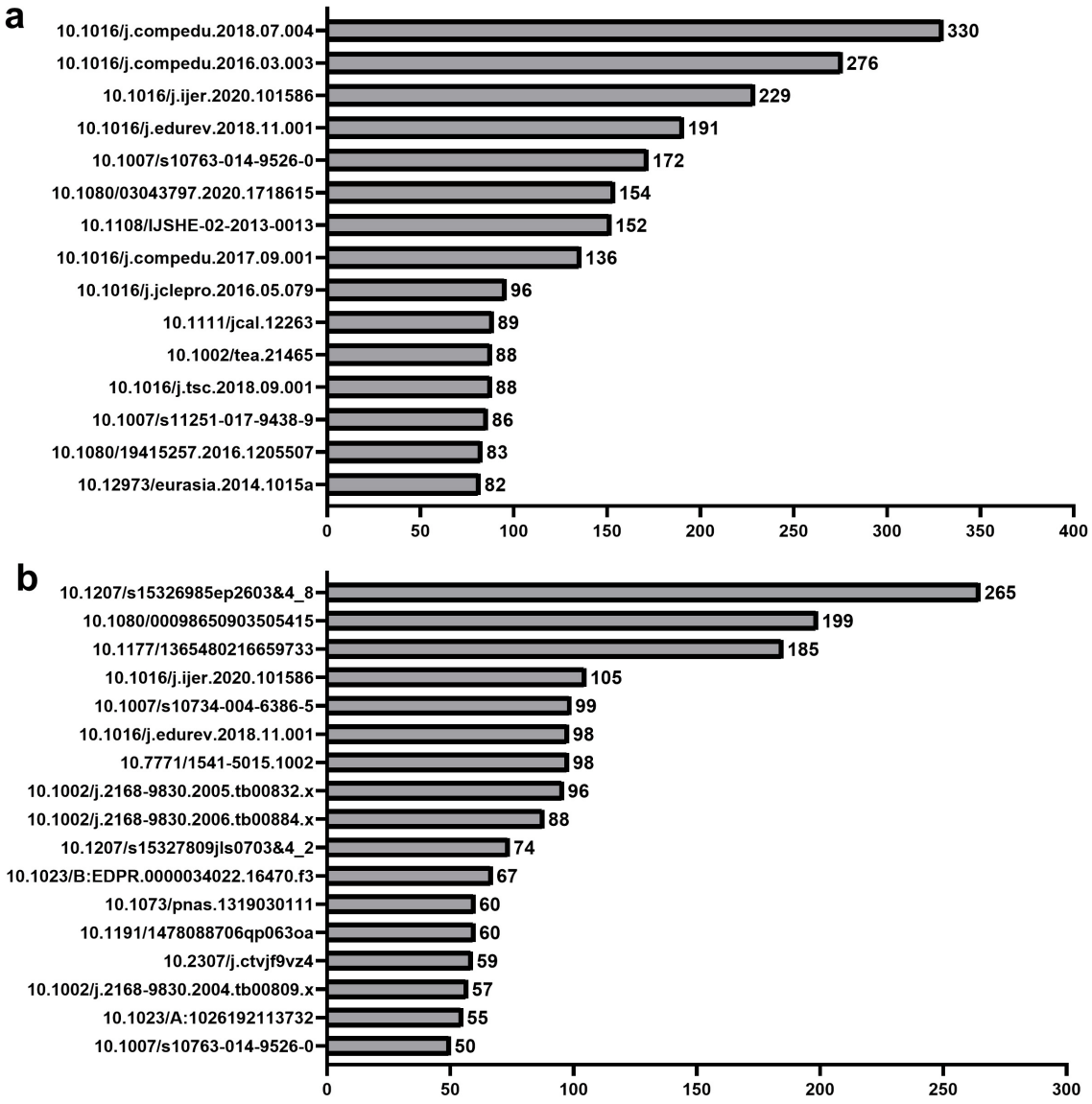

FIGURE 7
Articles's citation in WoS and authors' cited references. **(A)** DOIs of articles in our dataset that received 82 or more citations in WoS. **(B)** DOIs of references cited by the articles in our dataset, where each reference has 50 or more citations.

PjBL (Rodriguez-Sanchez et al., 2024). PjBL's emphasis on creating tangible artifacts or products distinguishes it, particularly in fields like engineering, where the design and creation of prototypes or models are central to the learning process (Helle et al., 2006). In the literature, it is possible to find cases where both PBL and PjBL are applied comparatively (Milla Pino et al., 2024; Rodriguez-Sanchez et al., 2024; Wijnia et al., 2024) or simultaneously (Habbal et al., 2024).

Our findings also indicate a strong regional focus in PjBL research, with the USA, Spain, and China leading in publications and network centrality. In the USA, PjBL is embedded in both K-12 and higher education, particularly within STEM disciplines, where practical and collaborative approaches are seen as essential to preparing students for future careers in science and technology (Blumenfeld et al., 1991; Boaler, 1998). This approach has a long history in the USA, dating back to the 1920s and 1930s when PjBL was widely used in elementary and secondary schools (Zhang and Ma, 2023). Recently, a shift toward more student-centered pedagogies reflects renewed efforts to enhance student engagement and real-world problem-solving skills in the country (Pupik Dean et al., 2023). The USA also stands out in the network analysis as the most central country in PjBL research, with the highest degree of connections and the most frequent collaborations, particularly with China (Chu et al., 2017b), Germany (Birdman et al., 2022) and Australia (Lobczowski et al., 2021).

Spain's contributions may be linked to national educational priorities that emphasize the development of competencies to address complex and evolving challenges. The Conference of Chancellors of Spanish Universities (CRUE) recommended curricula that focus on training proactive professionals capable of leading educational projects related to Education for Sustainable Development (ESD), which aligns with PjBL's strengths in fostering critical thinking and collaborative problem-solving (del Carmen Granado-Alcón et al., 2020). Meanwhile, China's growing role

in PjBL research reflects broader educational reforms aimed at fostering innovation and practical skills in engineering and technology. Traditionally focused on content-oriented teaching, Chinese universities are increasingly adopting project-based learning to enhance creativity, collaboration, and self-direction among students, aligning with the country's push for global competitiveness (Xu and Liu, 2010). The increase in publications from Indonesia may be related to the introduction of the "Merdeka Belajar" reform in 2019 (Hunaepi and Suharta, 2024). This reform aimed to overhaul Indonesia's education system by increasing the use of more student-centered approaches, including PjBL, to improve learning outcomes (OECD, 2024). This reform has turned Indonesia into a laboratory for PjBL-related research (Hunaepi and Suharta, 2024).

International collaboration plays a key role in advancing PjBL research, as evidenced by the network of organizations. The collaboration between AAU and QU is the most common and is particularly illustrative of how PjBL has transcended national borders, fostering international research collaboration that includes, e.g., investigations on engineering students' perceptions of their ability in Qatar (Du et al., 2022), and the development of engineering identity in Denmark (Chen et al., 2023). Similarly, collaborations between geographically close organizations like the UM and MSU show how PjBL has fostered interdisciplinary research, including studies on the effectiveness of wikis for collaborative learning (Chu et al., 2017b) and the development of competencies in sustainability education (Birdman et al., 2022). Other examples of frequent collaboration include HKU and BNU, as seen in investigations on sustainable PjBL through computer-based scaffolding for high- and low-achieving students (Peng et al., 2022) and research on secondary students' engagement in complex problem-solving processes within STEM projects (Wu et al., 2023). Overall, the network analysis of organizations reveals a diverse and decentralized collaboration landscape in PjBL research. IU emerges as the most connected institution, ranking highest in DC and EC, suggesting a strong position within the network and influence on other key institutions. The UC leading in BC indicates that it plays a relevant intermediary role in facilitating knowledge flow between different research groups. Meanwhile, MSU and HKU ranking first in WDC suggests that these institutions have the most intensive collaborations in the network. With the highest CC of the network, UPM, UM, and UNY are the ones with the shortest and most efficient paths to other institutions, meaning that they serve as efficient hubs, enabling rapid access to and dissemination of research within the network.

The high citation counts of certain articles in our selection also highlight key areas of impact within the PjBL literature. For instance, the two most highly cited studies underscore the role of digital technologies in enhancing PjBL approaches (Hsu et al., 2018; Sáez-López et al., 2016). While Sáez-López et al. (2016) focus on a case study for Scratch programming into PjBL to enhance student engagement in computer science education, Hsu et al. (2018) highlight the growing role of computational thinking within PjBL environments, emphasizing how integrating technology into education helps students adapt to future challenges. These studies reveal a growing trend in the use of technology to support collaborative learning, particularly in online or hybrid environments. As education increasingly integrates digital tools, PjBL's adaptability to technology-enhanced learning environments makes it a relevant approach for the future (Kokotsaki et al., 2016; Meng et al., 2023).

As for the references cited by the articles in our selection, the most highly cited reflect key foundational works in the field of education and PjBL (Bell, 2010; Blumenfeld et al., 1991; Kokotsaki et al., 2016). Blumenfeld et al. (1991) highlight the potential of PjBL to motivate students by engaging them in real-world, problem-solving activities that foster deep cognitive engagement. The study underscores the importance of project design in enhancing both student motivation and learning, emphasizing the role of teachers in scaffolding instruction and using technology to support learning. On the other hand, Kokotsaki et al. (2016) focus on the collaborative and student-centered nature of PjBL, identifying key factors that facilitate its successful implementation in various educational contexts. Finally, Bell (2010) emphasizes the role of PjBL in fostering critical 21st-century skills such as collaboration, self-reliance, and problem-solving.

This study has some limitations. While relying on a single database limits the range of articles analyzed, this approach is common in bibliometric and network studies. Merging metadata from different databases presents methodological challenges, such as combining fields with different standardization and coverage. Although databases like Scopus and PubMed are relevant for bibliometric research, we chose WoS for its broad coverage in education, inclusion of Impact Factor journals, high-quality metadata, and diverse analytical fields (de Andrade Gomes et al., 2024; Lopes et al., 2024). Still, some analyses do benefit from using multiple databases, particularly for periods not fully captured by a single source (Mota et al., 2022).

5 Conclusion

Our study highlights the expanding global interest and significant growth in PjBL research over the past 10 years. The 800% increase in publications between 2014 and 2023, particularly in STEM education and higher education, signals a recognition of PjBL's value in fostering critical 21st-century skills like problem-solving, collaboration, and self-regulation. The USA, Spain, and China have emerged as key contributors, with the USA leading in publications and collaborations, reflecting the country's central role in PjBL research. Strong connections with areas like Engineering and Computer Science add to the interdisciplinary nature of PjBL, particularly within fields that emphasize hands-on, inquiry-based learning. This nature is also seen in the use of terms such as "STEM," "higher education," and "engineering education" in keyword networks, which further supports the use of PjBL in fields where practical application of knowledge and collaborative problem-solving are key to preparing students for real-world challenges. These findings suggest that PjBL will continue to play a role in global educational reforms, promoting deeper engagement and preparing students for future careers in a rapidly changing technological and scientific world.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

FM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing – original draft, Writing – review & editing. BC: Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. LB: Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. RL: Conceptualization, Investigation, Supervision, Writing – review & editing.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Gen AI was used in the creation of this manuscript.

Publisher's note

Supplementary material

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