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Trends and Patterns in Project-Based Learning for Mathematics Education: A Global Bibliometric Analysis

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Abstract

Project-Based Learning (PjBL) has become an essential pedagogical approach in mathematics education, fostering critical thinking, problem-solving and student engagement. As its implementation continues to expand, a bibliometric analysis is necessary to examine the prevailing landscape, emerging trends, leading contributors and core research themes in PjBL mathematics education research. This study analyzes 246 Scopus-indexed publications (2006–2025) using OpenRefine, biblioMagika® and VOSviewer for data processing and visualization. The findings indicate a steady increase in PjBL research, with Indonesia and the United States leading contributions, reflecting strong policy support for STEM integration and student-centered learning. Thematic analysis identifies STEM education, teacher preparation and technology-enhanced learning as dominant research clusters, while creativity and computational thinking emerge as supporting themes. These insights highlight the evolving role of PjBL in mathematics education. Future research should explore long-term outcomes, digital learning advancements and interdisciplinary applications to further enhance PjBL's effectiveness in developing mathematical reasoning and real-world problem-solving abilities.

Introduction

In the evolving landscape of mathematics education, Project-Based Learning (PjBL) has emerged as a transformative pedagogical approach that fosters critical thinking, problem-solving and deep conceptual understanding (Rehman et al., 2023). Unlike traditional instruction, which often emphasizes procedural fluency, PjBL engages students in constructing mathematical knowledge through hands-on, inquiry-driven projects that require real-world application (Sulaiman et al., 2024). A defining characteristic of PjBL is that students actively produce mathematical products that demonstrate their ability to apply theories, analyze data and synthesize information creatively (Suryanti et al., 2024). Research suggests that PjBL strengthens student engagement, enhances self-confidence and supports deeper retention of mathematical concepts (Williamson, 2024). Through collaborative learning environments, students refine their reasoning skills, develop innovative problem-solving

strategies and construct knowledge autonomously (Gaikwad et al., 2024).

Theoretical foundations of PjBL are rooted in constructivist learning theories, which emphasize student-centered exploration and contextualized learning (Vygotsky, 1978). Social constructivism further supports collaboration as a core mechanism in mathematical meaning-making, where peer interactions and discourse enhance conceptual understanding and higher-order thinking (Bruner, 1986; Thompson, 2020). Moreover, PjBL's effectiveness is heightened through technology integration, which allows students to engage with digital simulations, AI-driven assessments and interactive mathematical modeling tools (Yunita et al., 2021). Recent advancements in technology-enhanced PjBL demonstrate that virtual learning environments, online collaboration platforms and dynamic mathematical visualization tools significantly improve students' engagement, self-regulation and problem-solving efficiency (Nguyen et al., 2024). Digital resources not only accelerate information access but also personalize learning experiences, making mathematics more accessible, interactive and intellectually stimulating (Sari et al., 2022).

Furthermore, creativity is an essential element in PjBL, as students are required to generate original solutions, approach problems from multiple perspectives and construct mathematical representations that are meaningful (de Oliveira Biazus et al., 2022). Creativity in mathematics is increasingly recognized as a crucial skill in mathematics education, supporting students' ability to innovate, adapt and think flexibly (Sánchez et al., 2022). The integration of creativity with PjBL further enhances students' capacity to generate diverse problem-solving strategies, particularly when technology is leveraged as a cognitive tool (Ortiz-Laso et al., 2023). However, despite its potential, the role of creativity in PjBL mathematics education remains underexplored, warranting further investigation into how technology-driven PjBL fosters mathematical creativity and critical reasoning.

Despite the growing recognition of PjBL's role in mathematics education, there remains a critical gap in understanding its global research trends, implementation effectiveness and long-term impact. Previous studies have primarily focused on PjBL's benefits in fostering engagement and conceptual understanding (Yunita et al., 2021). However, few studies have systematically analyzed how PjBL research has evolved, what themes dominate the field and how different regions and institutions contribute to its development. Many studies discuss how technology and creativity help in teaching mathematics, but few have analyzed how these topics appear in PjBL research using bibliometric methods. To address this gap, this study conducts a systematic bibliometric analysis of PjBL in mathematics education, examining global research trends, collaboration networks and emerging thematic focuses. By leveraging Scopus-indexed data and advanced bibliometric tools, this study seeks to identify influential research contributions, highlight evolving themes and provide insights for future research directions. This analysis will contribute to a comprehensive understanding of PjBL's trajectory, offering valuable implications for educators, policymakers and researchers seeking to optimize PjBL strategies in mathematics education.

Literature Review

Project-Based Learning (PjBL) has been widely adopted in mathematics education due to its ability to foster student engagement, critical thinking and problem-solving skills (Rehman et al., 2023). Unlike traditional

instruction, which prioritizes procedural fluency, PjBL encourages students to apply mathematical concepts through inquiry-based hands-on projects (Williamson, 2024). A key feature of PjBL in mathematics is that students produce meaningful mathematical products, integrating theoretical knowledge, data analysis and model construction (Suryanti et al., 2024). Research suggests that students in PjBL environments exhibit higher motivation and conceptual retention, as they engage in collaborative problem-solving and real-world applications (Williamson, 2024).

Despite its benefits, implementing PjBL in mathematics education presents challenges. Educators often struggle with curriculum constraints, assessment alignment and time limitations, making it difficult to integrate student-driven inquiry into structured curricula (Farrow et al., 2024). Additionally, teacher preparedness plays a crucial role, as many educators lack training in designing and managing PjBL tasks that maintain mathematical rigor (Nguyen et al., 2024). Research highlights that student participation in PjBL varies based on factors such as prior knowledge, collaboration skills and self-regulation abilities (Suryanti et al., 2024). Addressing these challenges requires professional development programs and instructional strategies that integrate PjBL with formative assessments (Gaikwad et al., 2024).

The foundations of PjBL in mathematics are rooted in constructivist and social constructivist learning theories (Vygotsky, 1978). Constructivist perspectives emphasize that students learn best by actively constructing knowledge, making PjBL an effective approach to developing mathematical reasoning (Thompson, 2020). Social constructivism further highlights the role of peer collaboration in strengthening mathematical understanding, as students engage in discussions, problem-solving and knowledge sharing (Binsaleh & Matcha, 2024). Additionally, cognitive load theory suggests that well-structured PjBL tasks with scaffolding help students navigate complex mathematical concepts effectively (Handayani et al., 2024).

Technology has significantly improved PjBL implementation in mathematics, providing interactive digital tools, real-time feedback and dynamic problem-solving environments (Nasution et al., 2021). Virtual simulations, AI-driven tutoring systems and collaborative platforms allow students to visualize mathematical models and test problem-solving strategies in real time (Nguyen et al., 2024). Studies highlight that technology-integrated PjBL fosters self-regulation, engagement and deeper conceptual understanding (Yunita et al., 2021). Additionally, blended learning models that combine face-to-face instruction with digital PjBL resources enhance accessibility and personalized learning experiences (Sari et al., 2022). However, challenges such as limited teacher training, resource availability and digital literacy gaps still need to be addressed for effective technology integration in PjBL (Sulaiman et al., 2024).

Beyond conceptual understanding, creativity is an essential yet underexplored element of PjBL in mathematics (Rehman et al., 2024). Creativity in problem-solving involves flexibility, originality and diverse thinking strategies, allowing students to explore multiple solution pathways and develop innovative mathematical representations (Rabia et al., 2024). PjBL supports creative mathematical thinking by encouraging students to construct models, analyze patterns and develop meaningful solutions. Additionally, technology enhances creativity in PjBL by enabling students to use digital tools, coding and simulations for mathematical exploration

(Sánchez et al., 2022). However, teachers require specialized training to effectively integrate creativity within PjBL mathematics instruction (Sánchez et al., 2022).

Although PjBL research in mathematics education has expanded significantly, gaps remain in understanding global research trends and key thematic developments. Most studies focus on student engagement, problem-solving and assessment, but few have systematically mapped how PjBL research has evolved over time (Nguyen et al., 2024). Additionally, while research highlights the importance of technology and creativity in PjBL, there is limited bibliometric evidence analyzing these trends globally (Sulaiman et al., 2024). Understanding which regions, institutions and authors are leading PjBL research, how collaboration networks are evolving and what themes dominate the field is crucial for advancing effective instructional practices in mathematics education. To address this gap, this study conducts a bibliometric analysis of PjBL research in mathematics education, examining publication trends, research collaboration networks and emerging research themes. Using Scopus-indexed publications and bibliometric tools, this study aims to identify influential research contributions, track thematic developments and provide insights for future research directions. The findings will offer valuable implications for educators, policymakers and researchers, contributing to the optimization of PjBL strategies in mathematics education and ensuring that students develop the problem-solving, critical thinking and creativity skills necessary for success.

Research Questions

This study conducts a comprehensive bibliometric analysis of Project-Based Learning (PjBL) in mathematics education research, addressing four principal research questions (RQs):

RQ 1: What is the prevailing landscape of PjBL research in mathematics education?

RQ 2: What emerging trends are identifiable within PjBL focused mathematics education publications?

RQ 3: Which countries are leading progress in PjBL related mathematics education research?

RQ 4: What core research themes emerge from the co-occurrence analysis of PjBL research in mathematics education?

Methodology

This study utilized data from the Scopus database, retrieved on February 13, 2025, due to its extensive coverage of peer-reviewed literature. Scopus was chosen for its broad disciplinary scope, particularly in mathematics, making it suitable for bibliometric analysis. Known for high-quality indexing and global reach, it provides valuable metadata such as citation metrics and author affiliations. The dataset included document types, source types, languages, subject areas, publication trends, authorship patterns, institutional contributions, geographic distribution and prevalent keywords, enabling a comprehensive analysis of Project-Based Learning research in mathematics education.

Search Strategy

The review adopted the modified PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for conducting systematic reviews (Moher et al., 2009). The search query ("Project-Based Learning" OR "Project Based Learning" OR "PBL" OR "PjBL") AND ("Math*" OR "Mathematics") AND ("Educat*" OR "Learn*" OR "Teach*" OR "Pedagog*") was applied in the Scopus database, followed by subject-specific filters. The search scope included parameters such as search field, time frame, source type and document type to exclude irrelevant studies. This process initially identified 1,494 documents (see Fig. 1). Abstract screening was then conducted to remove records lacking topical relevance. Following this filtering process, 220 documents on Project-Based Learning in mathematics education were retained for final analysis.

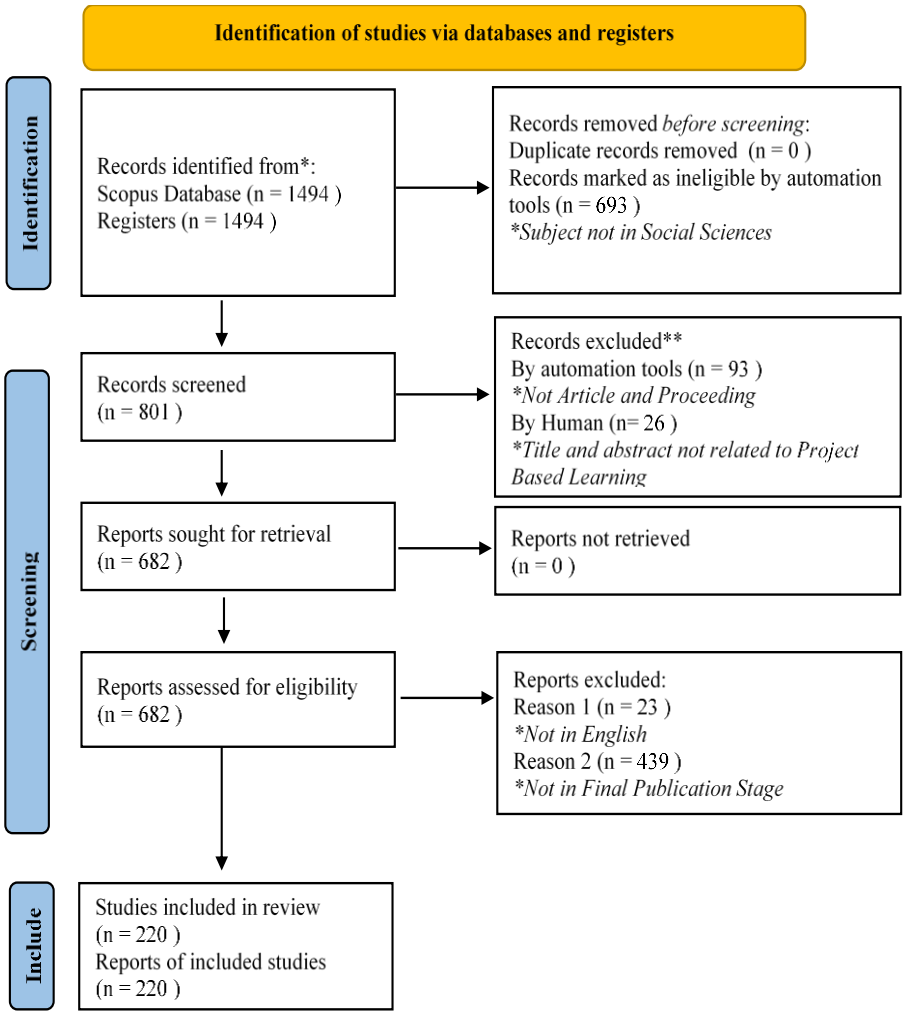

Figure 1. Flow Diagram of The Search Strategy

Data Cleaning and Harmonisation

Ensuring accuracy and reliability in bibliometric analysis requires effective data cleaning and harmonisation. In this study, OpenRefine and biblioMagika® (Ahmi, 2023) were employed to refine bibliographic data, including author names, affiliations and keywords, ensuring consistency across diverse research outputs. The data preparation process began with extracting Scopus records in CSV format, where selected files and columns

underwent refinement using clustering techniques. To facilitate advanced bibliometric analysis, biblioMagika® computed key indicators such as Total Publications (TP), Number of Contributing Authors (NCA), Number of Cited Publications (NCP), Total Citations (TC), Citations per Publication (C/P), Citations per Cited Publication (C/CP), Citations per Author (C/A), Authors per Publication (A/P), Citations per Year (C/Y), h-index, g-index, m-index and the Citation Sum within the h-Core. These indicators were analysed across various parameters, including publication year, source titles, authors, institutions and countries. Additionally, biblioMagika® detected missing data, allowing manual completion to enhance dataset integrity. The application of these tools improved the overall quality of the dataset, ensuring greater clarity and reliability in the exploration of Project-Based Learning in mathematics education.

Data Analysis

The data analysis in this study was systematically designed to address research questions concerning Project-Based Learning in mathematics education. A structured approach was employed to examine the current research landscape, considering aspects such as document type, source type, language distribution, subject areas and citation metrics. The findings were categorized based on annual publication trends and contributions from key countries, effectively identifying significant contributors and emerging patterns in PjBL within mathematics education. To evaluate the impact and significance of the publications, various bibliometric indicators were applied, including total publications, number of cited papers, total citations, citations per publication, citations per cited publication, h-index, g-index, m-index and cumulative citation count within the h-core. Furthermore, co-occurrence network analysis, thematic mapping and factorial analysis were utilized to visualize keyword relationships, allowing for the identification of thematic clusters and the detection of research patterns across different subfields of PjBL in mathematics education.

Tools

A range of tools was employed in this study to conduct an extensive bibliometric analysis. Microsoft Excel was used for initial data cleaning and structuring, while biblioMagika® facilitated the refinement, harmonization and standardization of author, affiliation and country-related data. OpenRefine was specifically utilized to improve consistency in authors' keywords. Once the data preparation phase was completed, VOSviewer was implemented to produce detailed visual representations of the research landscape, with Mendeley serving as the reference management system. The combination of these tools and analytical techniques provided a structured and in-depth examination of Project-Based Learning in mathematics education, ensuring a systematic and comprehensive assessment of the field.

Results

The upcoming results section presents an in-depth analysis of the research landscape surrounding Project-Based Learning in mathematics education. This structured examination directly addresses the research questions, providing valuable insights into the field. Through this focused approach, the study aims to offer a comprehensive

and substantive overview of PjBL in mathematics education, contributing essential knowledge that benefits researchers, educators and policymakers alike.

Prevailing Landscape of PjBL

This study examines the prevailing landscape of Project-Based Learning (PjBL) in mathematics education by analyzing the distribution of publications based on document type, source type, languages and subject areas. Citation metrics were also assessed to determine the impact and significance of research in this field. An analysis of publications from 2006 to 2025 reveals 246 documents, contributed by 807 authors, reflecting a strong collaborative effort. The dataset includes 197 cited papers, accumulating 3,050 total citations over 20 citable years, reinforcing the field's academic influence.

On average, each document has 12.40 citations, while cited papers average 15.48 citations, highlighting the recognition of impactful research. The annual citation rate of 160.53 further demonstrates ongoing scholarly engagement. The citation per author metric (3.78) and an author-per-paper ratio of 3.28 indicate frequent collaboration among researchers.

The citation sum within the h-core stands at 2,700, underscoring the impact of highly influential papers. Additionally, bibliometric indicators such as the h-index (28), g-index (45), and m-index (1.400) further validate the field's scholarly significance (see Table 1). These findings provide a comprehensive overview of the prevailing landscape, highlighting the growth and impact of PjBL research in mathematics education.

Table 1. Citation Metric

Main Information	Data
Publication Years	2006 - 2025
Total Publications	246
Citable Year	20
Number of Contributing Authors	807
Number of Cited Papers	197
Total Citations	3,050
Citation per Paper	12.40
Citation per Cited Paper	15.48
Citation per Year	160.53
Citation per Author	3.78
Author per Paper	3.28
Citation sum within h-Core	2,700
h-index	28
g-index	45
m-index	1.400

Emerging Trends

To examine the emerging trends in Project-Based Learning (PjBL) research within mathematics education, this study analyzed the trajectory of publications and citation patterns over time. The earliest recorded study in this field appeared in 2006, with research activity steadily increasing in later years. As shown in Table 2, the total number of publications has reached 246, contributed by 246 authors, indicating a growing and dynamic research community.

A consistent rise in research output is evident, with notable publication peaks in 2017, 2020 and 2023, where the total number of publications stood at 9, 29 and 37, respectively. The most significant citation impact per paper occurred in 2017, with an average of 55.56 citations per publication, highlighting the lasting influence of studies from that period. The cumulative citation count has reached 3,050, reflecting sustained academic interest in PjBL research in mathematics education.

Key bibliometric indicators, including the h-index (28) and g-index (45), suggest the presence of highly cited and impactful studies in the field. The m-index, which peaked at 2.667 in 2023, indicates strong research momentum. However, lower citation counts in 2024 and 2025 reflect the expected lag in citation accumulation for newly published studies. These emerging trends suggest a growing interdisciplinary interest in PjBL in mathematics education, characterized by increasing collaboration among authors and rising citation metrics. The data indicate that this research area continues to expand, warranting further exploration of key thematic developments and the evolving scholarly impact of PjBL.

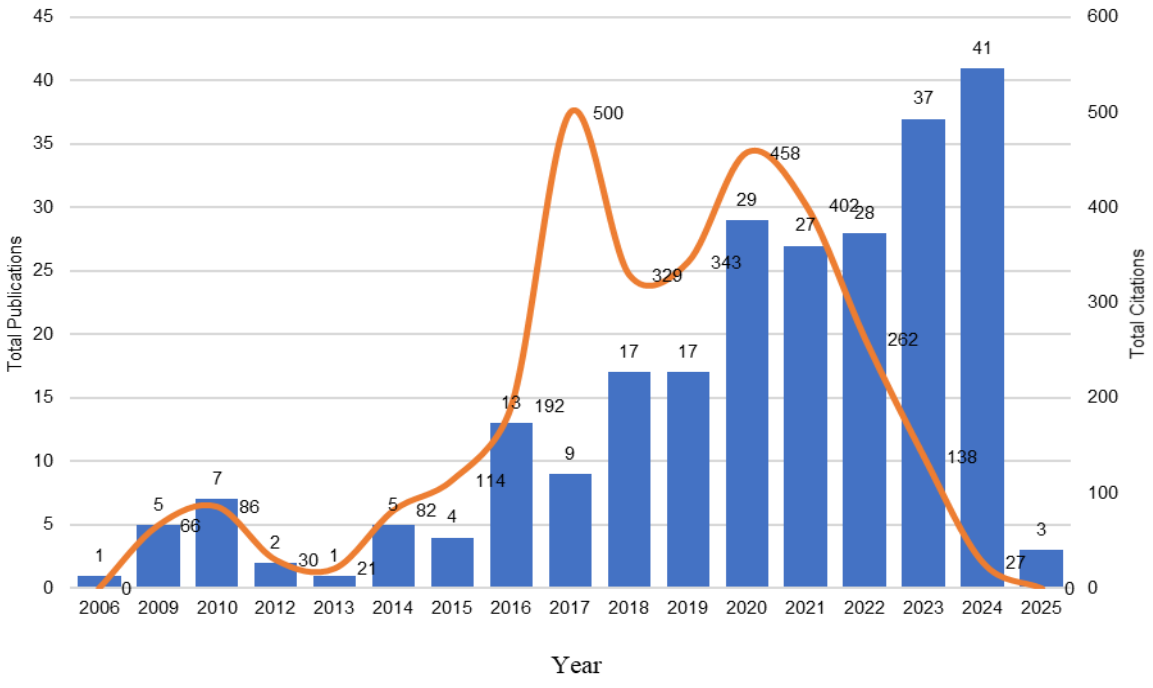

Figure 2. Total Publications and Citations by Year (Excluding the Year 2025 as Data is Only Available Up to 13 February 2025)

Table 2. Publication by Year

Year	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
2006	1	1	0	0	0.00	0.00	0	0	0.000
2009	5	5	5	66	13.20	13.20	2	5	0.118
2010	7	7	7	86	12.29	12.29	6	7	0.375
2012	2	2	2	30	15.00	15.00	2	2	0.143
2013	1	1	1	21	21.00	21.00	1	1	0.077
2014	5	5	5	82	16.40	16.40	4	5	0.333
2015	4	4	3	114	28.50	38.00	3	4	0.273
2016	13	13	12	192	14.77	16.00	7	13	0.700
2017	9	9	9	500	55.56	55.56	8	9	0.889
2018	17	17	17	329	19.35	19.35	9	17	1.125
2019	17	17	17	343	20.18	20.18	9	17	1.286
2020	29	29	29	458	15.79	15.79	13	21	2.167
2021	27	27	25	402	14.89	16.08	12	19	2.400
2022	28	28	22	262	9.36	11.91	10	15	2.500
2023	37	37	25	138	3.73	5.52	8	10	2.667
2024	41	41	18	27	0.66	1.50	3	3	1.500
2025	3	3	0	0	0.00	0.00	0	0	0.000
Grand Total	246	246	197	3050	12.40	15.48	28	45	1.400

Notes: TP = total number of publications; NCA = number of contributing authors; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index; m = m-index.

* Publication data for the year 2025 is only up until 13 February 2025.

Leading Countries

To identify the leading countries driving progress in Project-Based Learning (PjBL) research within mathematics education, this study analyzed the distribution of publications and citation impact by country. Table 3 and Figure 3 present the research output of nations that have made significant contributions to PjBL, focusing on those with at least 15 publications. Indonesia emerges as the most prolific contributor, with 188 publications and 2,123 total citations, reflecting its strong research presence. It maintains an h-index of 22, indicating the influence of its highly cited studies. The United States follows closely, producing 164 publications with the highest citation count (2,393 citations) and an h-index of 23, reinforcing its academic prominence in PjBL research.

Malaysia holds a notable position with 61 publications and 532 citations, maintaining an h-index of 12, while Spain (56 publications, 697 citations) and Taiwan (30 publications, 1,060 citations) also contribute significantly. Australia, with 22 publications and 528 citations, demonstrates steady research engagement in PjBL within mathematics education. Additionally, emerging research contributions from Russia, India and China, each with

15 to 17 publications, highlight the broadening global engagement in PjBL research. The geographic distribution of studies underscores the growing international interest and collaboration in integrating PjBL into mathematics education, reflecting both established and developing contributions to the field.

Table 3. Countries that Contributed 15 or More Publications

Country	TP	NCP	TC	C/P	C/CP	h	g	m
Indonesia	188	161	2123	11.29	13.19	22	46	1.375
United States	164	127	2393	14.59	18.84	23	48	1.150
Malaysia	61	48	532	8.72	11.08	12	23	0.750
Spain	56	49	697	12.45	14.22	19	26	1.462
Taiwan	30	30	1060	35.33	35.33	21	30	1.750
Australia	22	14	528	24.00	37.71	11	22	1.100
Russian Federation	17	17	189	11.12	11.12	9	13	1.000
India	16	14	51	3.19	3.64	4	7	0.500
Italy	16	16	343	21.44	21.44	8	16	1.000
Austria	15	15	67	4.47	4.47	3	8	0.429
China	15	14	184	12.27	13.14	11	13	1.375
Turkey	15	15	208	13.87	13.87	7	14	0.412

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index; m = index

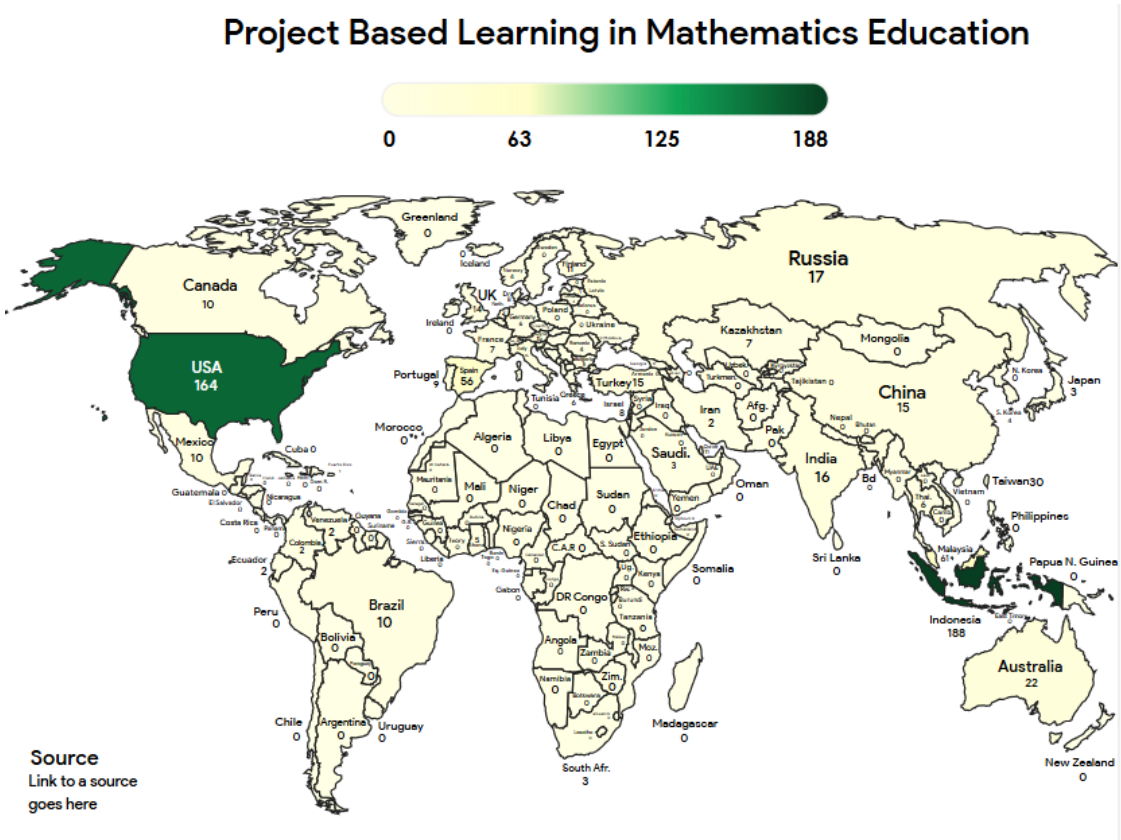

Figure 3. Visualization of Global Distribution of SDL Research Publications

Co-occurrence Analysis of Core Research Themes in PjBL

The final research question, "What core research themes emerge from the co-occurrence analysis of PjBL research in mathematics education?" guided a thematic investigation to identify dominant research themes and their interconnections. This analysis mapped frequently occurring author keywords, revealing critical thematic areas shaping Project-Based Learning (PjBL) in mathematics education. Figure 4 presents a detailed co-occurrence network, illustrating the thematic structure of PjBL research. The network visually represents key areas of scholarly focus, with larger nodes and stronger connections highlighting frequently discussed research topics. At the center of the network, “project-based learning” and “problem-based learning” emerge as dominant themes, indicating their central role in mathematics education research.

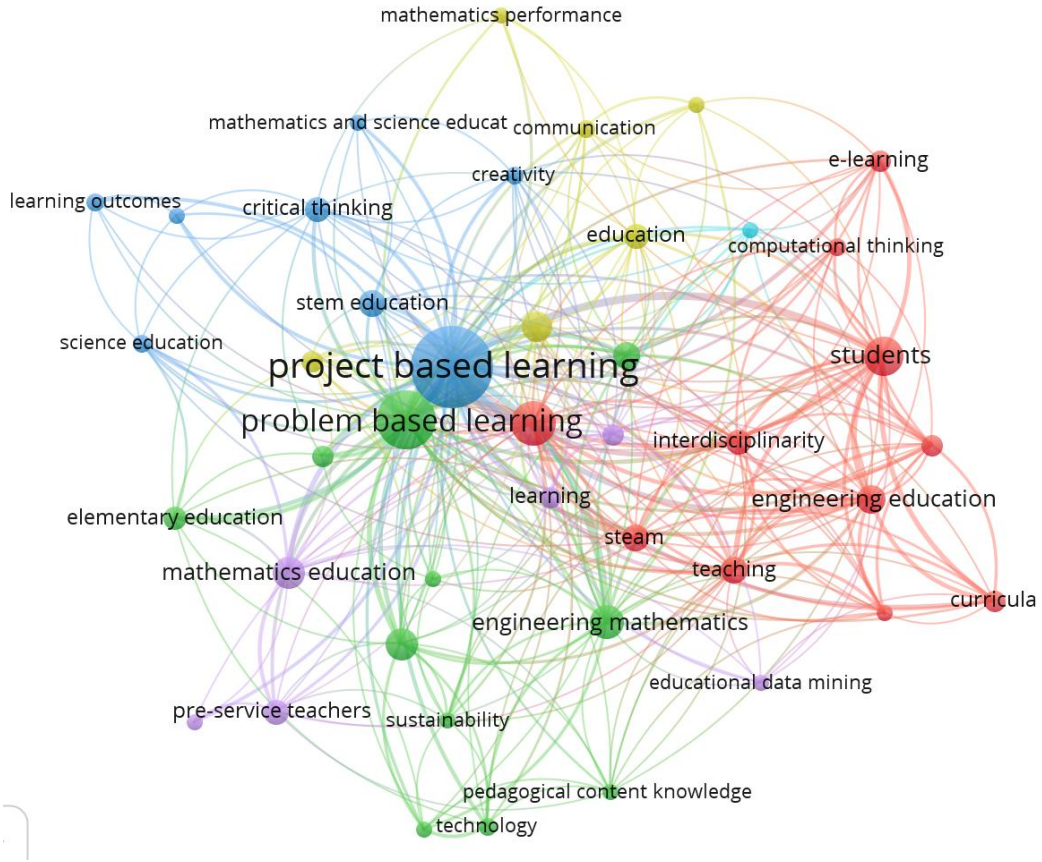

Figure 4. Co-occurrence Network of The Author’s Keywords with At Least 2 Occurrences

The co-occurrence network of author keywords in Figure 4 highlights research themes appearing at least twice, providing insights into key focus areas in PjBL research. A closer examination reveals distinct thematic clusters, each representing an important direction in PjBL’s integration into mathematics education. The blue cluster is centered on "STEM education", "critical thinking" and "learning outcomes", highlighting the increasing role of PjBL in developing analytical reasoning and real-world problem-solving skills. The association with science education and mathematics performance suggests that interdisciplinary connections enhance students' ability to apply mathematical knowledge in practical contexts. This supports the argument that PjBL is instrumental in fostering deeper conceptual understanding and knowledge retention in mathematics education.

The red cluster links PjBL with e-learning, computational thinking and engineering education, reflecting the growing role of digital tools and online learning environments in mathematics instruction. The inclusion of students, curricula and interdisciplinary learning within this cluster emphasizes the importance of aligning PjBL approaches with evolving educational frameworks. As technology-enhanced learning environments gain prominence, PjBL research increasingly focuses on how technology can facilitate engagement, self-regulation and interactive learning experiences.

The green cluster connects mathematics education, teacher education and pedagogical content knowledge, indicating the crucial role of teacher preparation in implementing PjBL effectively. The relationship between pre-service teachers and sustainability suggests that PjBL is not only a student-centered learning approach but also a strategy for long-term educational transformation. The integration of technology and pedagogical training within this cluster reinforces the need for professional development programs that equip teachers with the skills to implement PjBL effectively in mathematics education.

The co-occurrence analysis highlights that PjBL research in mathematics education is strongly associated with STEM education, technology-enhanced learning and teacher training. The presence of creativity within the network suggests its emerging importance in PjBL, particularly in encouraging innovative problem-solving and mathematical reasoning. These findings indicate that future research should further explore how digital tools, creativity and interdisciplinary collaboration enhance PjBL's effectiveness. Strengthening these research connections will contribute to innovative instructional strategies, ensuring that students develop the critical thinking, problem-solving and applied mathematical skills needed to succeed in an evolving educational landscape.

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Discussion

This study presents a bibliometric analysis of Project-Based Learning (PjBL) research in mathematics education, focusing on its growth, emerging trends, geographic distribution and core research themes. Findings indicate a steady rise in PjBL research from 2006 to 2025, with 246 publications indexed in Scopus. This expansion reflects increasing recognition of student-centered learning, problem-solving and interdisciplinary instruction. Global education reforms promoting active learning strategies in mathematics have driven this growth. The rising citation impact and expanding research collaborations suggest a sustained scholarly interest in enhancing PjBL methodologies to improve mathematical reasoning, student engagement and real-world application.

The publication trends highlight key emerging themes. Research output has increased steadily, with significant peaks in 2017, 2020 and 2023, coinciding with the rise of STEM education and technology-enhanced learning. Studies published in 2017 had the highest citation impact, demonstrating the enduring influence of foundational research. While more recent publications from 2024 and 2025 show lower citation counts due to time lag, the steady increase in research suggests continued relevance. Authorship patterns reveal a shift toward collaborative and interdisciplinary research, further expanding PjBL's academic impact. The h-index (28) and g-index (45) confirm the influence of frequently cited works, while the m-index peaked at 2.667 in 2023, reflecting strong

research momentum.

Geographic analysis identifies Indonesia (188 publications, 2,123 citations) and the United States (164 publications, 2,393 citations) as leading contributors, driven by national education policies promoting active learning. Malaysia, Spain and Taiwan also play significant roles, while countries like Russia, India and China demonstrate emerging contributions. These trends highlight the diverse global engagement in PjBL research and suggest opportunities for increased collaboration to strengthen its adoption in mathematics education.

The co-occurrence analysis reveals three primary research themes in PjBL-focused mathematics education. First, PjBL's integration with STEM education emphasizes its role in fostering analytical reasoning, problem-solving and interdisciplinary learning. The connections between engineering mathematics, science education and computational thinking suggest PjBL's broader applications beyond traditional mathematics instruction. Second, teacher education and pedagogical content knowledge emerge as crucial themes, highlighting the need for professional development to equip educators with the skills to implement PjBL effectively. Research shows that pre-service teacher training and innovative instructional strategies are critical for successful PjBL adoption. Third, technology-enhanced learning appears as a dominant theme, underscoring the role of digital tools, interactive platforms and AI-driven assessments in facilitating student-centered learning. Creativity also emerges as a relevant but underexplored theme, reinforcing PjBL's potential to enhance students' innovative problem-solving skills, conceptual exploration and engagement in mathematical inquiry.

These findings highlight the need for further research into how AI-driven learning environments, adaptive digital tools and collaborative online platforms can optimize PjBL's effectiveness. Future studies should also explore how PjBL fosters long-term mathematical creativity, conceptual retention and problem-solving abilities. In conclusion, this study provides critical insights into the growth and thematic evolution of PjBL research in mathematics education. Strengthening instructional strategies, improving teacher training and leveraging emerging technologies will be crucial for maximizing PjBL's long-term impact on student learning and engagement.

Conclusion and Future Research

This bibliometric analysis provides a comprehensive examination of the prevailing landscape of Project-Based Learning (PjBL) in mathematics education, highlighting a steady increase in research publications from 2006 to 2025. Findings indicate that PjBL research has gained emerging recognition as an effective instructional strategy, aligning with global educational priorities that emphasize student engagement, critical thinking and interdisciplinary learning. Indonesia and the United States lead progress in PjBL-related mathematics education research, shaped by policies promoting technology integration, STEM-focused education and real-world problem-solving. The co-occurrence analysis identifies core research themes, including STEM education, teacher training and technology-enhanced learning, reflecting the emerging role of digital tools and innovative pedagogies in mathematics instruction. Future research should explore emerging trends in PjBL across various educational levels, particularly analyzing its impact in primary, secondary and tertiary mathematics education. Longitudinal

studies are needed to assess the prevailing influence of PjBL on mathematical reasoning, creativity and problem-solving. Additionally, given the growing role of technology, further research should examine how AI-driven learning environments, interactive simulations and collaborative virtual platforms can optimize progress in PjBL implementation. Expanding interdisciplinary collaboration will be essential to refining emerging PjBL methodologies and adapting them to diverse educational contexts. As PjBL continues to evolve, integrating digital tools and creative problem-solving approaches will be crucial for enhancing its effectiveness. This study offers valuable insights for educators, policymakers and researchers, supporting progress in innovative teaching strategies that enhance PjBL's role in mathematics education and foster student-centered learning.

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