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A Bibliometric Analysis of the Impact of Project-Based Assessment on Conceptual Understanding in STEM Education

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ABSTRACT This bibliometric analysis investigates the impact of Project-Based Assessments (PBAs) on conceptual understanding in STEM education from 2019 to 2024. By examining a dataset of 996 publications, the study highlights significant fluctuations in research outputs and the evolving focus on educational methodologies, particularly noting an intensification of activity during the COVID-19 pandemic 2021. The publication trends show an increase from 184 documents in 2019 to a peak of 263 documents in 2021, followed by a gradual decline to 30 documents in 2024, suggesting shifts in research priorities or the field's maturation. Through detailed citation patterns and publication metrics analysis, the research elucidates the effectiveness of PBAs in enhancing student engagement and interdisciplinary integration while improving pedagogical practices. Key findings indicate that PBAs significantly improve students' understanding of complex STEM concepts through hands-on, real-world problem-solving and enhance educators' capabilities in delivering innovative instruction. Additionally, the study explores the role of technological advancements, such as 3D printing, in PBL, assessing their impact on the teaching and learning processes. By synthesizing information across various studies, this research provides a comprehensive overview of the educational outcomes associated with PBL. It offers insights into its long-term efficacy and adaptability in diverse educational settings. This analysis presents valuable perspectives for educators, policymakers, and researchers, aiming to optimize STEM education practices globally.

Keywords: Project-based assessment, Conceptual understanding, STEM education

1. INTRODUCTION

The advancement of project-based assessment in STEM (Science, Technology, Engineering, and Mathematics) education reflects a critical shift towards interactive and integrative teaching methodologies that better prepare students for real-world challenges. In the context of an increasingly technological society, the efficacy of educational practices in cultivating necessary skills such as analytical thinking, creativity, and collaborative problem-solving is paramount. A study by Gao et al. (2020) highlights that project-based learning fosters a deeper understanding of scientific and mathematical principles and significantly enhances student engagement and motivation by linking academic concepts to real-world applications.

Bibliometric analysis emerges as a vital tool in this evolving educational landscape, providing a systematic method to track and analyze the progression of research on project-based assessments in STEM education. This analytical approach aids in mapping the trajectory of research trends, providing a clear picture of how methodologies and focus areas have evolved (Oya, 2024). By evaluating citation patterns and publication metrics, bibliometric studies offer insights into the core areas of focus and the evolution of thought within STEM education research. For instance, Lin et al. (2021) demonstrate the significant role of project-based learning in improving technological and engineering design skills, suggesting a strong correlation between hands-on project involvement and enhanced learning outcomes.

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One of the main challenges highlighted by recent studies, such as those by Hsu and Tsai (2022), is integrating project-based learning within existing curricula. Adapting traditional educational frameworks to include comprehensive project-based assessments requires careful consideration of curriculum goals, teaching resources, and student readiness. Bibliometric analysis aids in understanding these complexities by mapping out the connections between various research studies and their practical implications. This helps identify gaps where project-based learning might not align perfectly with educational standards or student needs, guiding future research and development in STEM education.

Moreover, the role of technology in enhancing the effectiveness of project-based learning is becoming increasingly apparent, as discussed by Rafeeq and Al-Mekhlafi (2021). Digital tools and platforms offer new ways to implement, track, and assess project-based learning activities, potentially increasing accessibility and providing richer data for evaluating student progress and engagement. When combined with advanced data analytics, bibliometric analysis allows for a more nuanced exploration of how digital transformation influences educational practices, revealing patterns that suggest how technological integration can make STEM education more effective and inclusive.

This comprehensive examination of project-based assessment through bibliometric analysis underscores its growing importance in STEM education. By synthesizing a wide range of studies, this approach highlights the benefits and challenges of these methodologies. It provides a roadmap for educators and policymakers aiming to enhance STEM learning environments. Integrating these findings into educational strategies ensures that teaching practices remain aligned with the latest research and are adapted to meet the evolving demands of the educational sector and the broader workforce.

1.1 Literature Review

Research Discussion on Project-Based Assessment on Conceptual Understanding in STEM Education

Project-based assessment in STEM education is crucial for enhancing students' conceptual understanding by providing a hands-on, practical approach to learning. By integrating project-based assessment methods, educators can effectively evaluate students' comprehension of STEM concepts through real-world problem-solving, collaboration, and application of engineering design processes (Mustafa et al., 2016). This approach fosters critical thinking skills and enhances students' confidence in pursuing STEM-related careers. Project-based assessment in STEM education aligns with the principles of integrated STEM education, emphasizing the interconnectedness of science, technology, engineering, and mathematics disciplines (Kelley & Knowles, 2016). By incorporating project-based assessment strategies, educators can address the challenges and obstacles associated with developing and implementing integrated STEM curricula and instruction (Shernoff et al., 2017). Furthermore, project-based assessment allows for a more equitable representation of all STEM disciplines, promoting a holistic understanding of STEM concepts (English, 2016).

Assessing students' conceptual understanding through project-based assessment involves a structured approach, including reviewing STEM literature, planning STEM methods courses, and incorporating expert evaluation and feedback for continuous improvement (Pimthong & Williams, 2021). This method evaluates students' knowledge and enhances their problem-solving abilities and literacy skills (Asrizal et al., 2023). Additionally, project-based assessment supports the development of 21st-century skills and encourages students to explore STEM careers (Dare et al., 2021).

Previous Research

Project-Based Assessments (PBAs) in STEM education have gained considerable attention in recent years due to their potential to enhance students' conceptual understanding through hands-on, practical approaches. Reviewing previous research in this area is essential for understanding PBAs' effectiveness and identifying existing literature gaps. This section highlights key studies that have contributed to the development of PBAs, including their application in real-world problem-solving, interdisciplinary learning, and the integration of digital tools. Each entry includes the research subject, data source, the year of publication, the tools or methodologies used, and the reference. By synthesizing these studies, we aim to provide a comprehensive overview of the current state of research on PBAs and their contributions to improving conceptual understanding in STEM education.

The exploration of project-based assessments (PBAs) in STEM education through bibliometric analysis has yielded significant insights, as summarized in Table 1. This table highlights ten key studies from 1993 to 2023 that have used advanced bibliometric tools such as VOSviewer and Microsoft Excel to map trends and progress in STEM education research. These studies focus on how PBAs and project-based learning strategies are employed to enhance conceptual understanding in STEM fields.

For example, Kahraman (2023) and Jamali et al. (2023) utilize advanced bibliometric tools to track the evolution and current trends within STEM education. These studies underscore the integration of project-based learning with conceptual understanding in a STEM context, demonstrating how assessments are aligned with interdisciplinary teaching practices and real-world applications. Aliu & Aigbavboa (2023) and Ali & Tse (2023) focus on the historical progression and thematic concentrations of construction and engineering design education within the broader framework of STEM. The study examined the evolution of project-based learning in

Table 1 Previous research discussing assessment projects in STEM education

No	Research Subject	Data source	Year	Application	Ref
1	Bibliometric and content analysis of meta-analysis studies in the field of STEM education	Google Scholar	2015 to 2023	VOSviewer	Kahraman (2023)
2	The role of STEM Education in improving the quality of education: a bibliometric study	Google Scholar	1993 to 2020	Microsoft Excel, VOSviewer	Jamali et al. (2023)
3	Reviewing the trends of construction education research in the last decade: a bibliometric analysis	Google Scholar	2010 to 2020	VOSviewer	Aliu & Aigbavboa (2023)
4	Research Trends and Issues of Engineering Design Process for STEM Education in K-12: A Bibliometric Analysis	Google Scholar	2011 to 2021	VOSviewer, Microsoft Excel	Ali & Tse (2023)
5	Research Progress of STEM Education Based on Visual Bibliometric Analysis	Google Scholar	2006 to 2021	VOSviewer, Microsoft Excel	Cai et al. (2023)
6	A bibliometric analysis of the global landscape on STEM education (2004-2021): Towards global distribution, subject integration, and research trends	Google Scholar	2004 to 2021	VOSviewer, Microsoft Excel	Zhan et al. (2022)
7	Project-based learning (PjBL)-STEM: Bibliometric analysis and research trends (2016-2020)	Google Scholar	2016 to 2020	VOSviewer, Microsoft Excel	Putri et al. (2021)
8	Strategies in language education to improve science student understanding during practicum in the laboratory: Review and computational bibliometric analysis	Google Scholar	2015 to 2021	VOSviewer,	Fauziah et al. (2021)
9	A Bibliometric Analysis of Project-Based Learning Research in and Outside Mainland China	Google Scholar	2000 to 2021	VOSviewer,	Lin et al. (2023)
10	A bibliometric and classification study of Project-based Learning in Engineering Education	Google Scholar	2000 to 2016	VOSviewer,	Reis et al. (2017)

construction and engineering education, showing how PBAs help develop engineering design thinking and problem-solving skills. Similarly, studies by Cai et al. (2023) and Zhan et al. (2022) mapped global trends in STEM education, illustrating how PBAs contribute to subject integration and the complexity of educational frameworks.

Other studies, such as Putri et al. (2021) and Fauziah et al. (2021), delve into applying PBAs in laboratory settings and their role in improving student understanding of scientific concepts. These findings underscore the potential of PBAs to enhance student engagement and learning outcomes by linking academic theory to practical, hands-on tasks. Lin et al. (2023) provide a comprehensive bibliometric analysis of project-based learning (PBL) research conducted in and outside Mainland China. The analysis reveals the increasing relevance of PBL in various educational contexts and its effectiveness in enhancing student learning outcomes in STEM disciplines. The findings underscore the global movement towards project-based methodologies, highlighting the impact of cultural and educational frameworks on the implementation of PBAs. Reis et al. (2017) focus on project-based learning in engineering education. They classify the literature into various themes and methodologies, providing insights into how PBAs have been integrated into engineering curricula. The study emphasizes the pedagogical advantages of using project-based learning to develop critical skills in engineering students, such as problem-solving, teamwork, and innovative thinking. The research highlights the importance of adapting project-based approaches to meet engineering education's evolving demands and prepare students for real-world challenges.

Overall, the studies summarized in Table 1 provide a comprehensive overview of how PBAs have been used in STEM education to foster deeper learning and conceptual understanding. This bibliometric review builds on these foundational works to examine the ongoing evolution of PBAs and their integration with technology, offering new insights into the future of STEM education.

2. METHOD

2.1 Research Design

The bibliometric review used a robust dataset from scholarly articles on "Project-Based Assessment on

Conceptual Understanding in STEM Education" from 2019 to 2024. The Publish or Perish software facilitated the retrieval of these articles, and it is renowned for its capacity to efficiently extract extensive bibliographic data from Google Scholar. Approximately 1,000 articles were initially retrieved using predefined search criteria relevant to PBAs in STEM education. Following retrieval, a systematic filtering process was implemented to ensure the dataset's relevance and quality. This process involved reviewing abstracts and full texts to identify studies explicitly focusing on PBAs rather than general project-based learning.

After the initial screening, 996 articles were retained for further analysis. The eliminated articles (4 in total) were primarily excluded for the following reasons:

- Lack of Relevance: Articles that did not specifically address PBAs or their impact on conceptual understanding in STEM.
- Insufficient Data: Publications that needed more methodological detail or empirical data were also excluded.
- Duplications: Any duplicate entries in the dataset were removed.

The final comprehensive dataset consisted of 996 articles, exported in CSV and RIS formats to enable a dual approach to data analysis. CSV files were primarily utilized for initial quantitative assessments and statistical analysis within Microsoft Excel. Simultaneously, RIS files were integral for advanced visualizations and network analyses using VOSviewer. This dual-format strategy ensured a thorough bibliometric evaluation, combining preliminary statistical exploration with intricate visual data mapping (Al Husaeni & Nandiyanto, 2022).

2.2 Sources of Data

The data preparation process began with an extensive filtering of the collected articles to ensure their relevance and completeness. Initially, 1,000 articles were retrieved, as mentioned in Section 2.1. During the initial screening, a careful review of the titles and abstracts was conducted to align the content with the study's thematic focus areas of "Project-Based Assessment," "Conceptual Understanding," and "STEM Education." After this initial screening, 996 articles were retained for further analysis, while 4 articles were eliminated. Once the filtering process was complete, the selected articles were organized in Microsoft Excel for preliminary statistical analysis. The dataset was subsequently prepared in VOSviewer for advanced visualizations and network analysis, allowing for a comprehensive bibliometric evaluation of the literature on PBAs in STEM education.

2.3 Procedure of Data Collection

The bibliometric analysis proceeded through several defined stages:

- Collection of Publication Data: Utilizing the Publish or Perish application, we gathered data from various scholarly publications indexed by Google Scholar, focusing on the relevant study period and subjects.
- Processing of Bibliometric Data: The articles obtained were then processed using Microsoft Excel to organize and perform initial statistical analyses. This stage involved sorting, manipulating, and preparing the data for deeper analysis.
- Computational Mapping Analysis: We used VOSviewer to conduct a detailed mapping analysis of the bibliometric data. This tool enabled the construction of co-citation and co-authorship networks and the mapping of keywords and thematic concentrations.
- Analysis of Computational Mapping Results: The mapping analysis's outcomes were then comprehensively reviewed to identify central themes, significant research contributions, and emerging trends within the domain of project-based assessment of conceptual understanding in STEM education.

2.4 Data Analysis

The statistical analysis employed in this study was two-pronged. Initially, Microsoft Excel facilitated the computation of basic statistical measures, such as frequency counts, means, and distributions of publications over time. This allowed for a foundational understanding of the dataset's quantitative attributes. VOSviewer's capabilities were utilized for more sophisticated analyses to compute and visualize more complex statistical relationships, such as those between co-occurring terms and citation networks. This involved calculating the total link strength and occurrences of terms to discern patterns and associations among them. These analytical procedures underpinned the quantitative findings of the bibliometric review, which served as the basis for qualitative interpretations and conclusions drawn from the visual data representations.

3. RESULT

3.1 The Impact of Project-Based Assessment on Conceptual Understanding in STEM Education 2019-2024

The data in "Table 2. Annual Report Research on 'Project-Based Assessment on Conceptual Understanding in STEM Education'" illustrates a notable fluctuation in publication numbers from 2019 to 2024, detailing the evolving focus within this educational research area. The total count of analyzed documents is 996, sourced from an original pool of 1,000 articles, highlighting an effective capture of the relevant literature. Initially 2019, 184 documents were published, which increased to 206 in 2020, indicating a growing interest in project-based assessment approaches. A significant publication surge was observed in 2021, with 263 documents, likely a response to the heightened demand for innovative teaching methodologies influenced by global educational shifts during the pandemic. However, post-2021, the numbers began to decrease: 171 publications in 2022, 142 in 2023, and a sharp decline to only 30 in 2024, possibly due to partial data collection for the current year or shifting research priorities.

This trend suggests a dynamic shift in research output, which may reflect a range of factors, including the maturation of research topics, changes in funding priorities, or a broader adaptation of project-based methodologies in practice, reducing the demand for further foundational research. The peak in 2021 highlights a period of intense academic activity driven by the need to address urgent educational challenges and opportunities presented by sudden shifts to remote learning environments. The subsequent decline could indicate that as the immediate challenges were increasingly addressed, the focus may have shifted towards refining and implementing the developed methodologies rather than exploring new conceptual grounds.

Moreover, the graphical representation in "Figure 1. Annual Report of Publications" visually corroborates these findings, showing a clear peak in 2021 followed by a gradual decline. Such patterns are essential for understanding the trajectory of academic research in STEM education, particularly the factors influencing the rise and ebb in scholarly focus. The initial increase and later decrease could reflect a cycle of innovation followed by implementation and assessment phases, typical in academic research cycles.

This comprehensive analysis not only illuminates the quantitative aspects of STEM education research but also invites reflection on the qualitative shifts that might underlie these trends. It emphasizes the need for ongoing support and adaptation in educational research to continuously enhance teaching practices and student outcomes in the ever-evolving landscape of STEM education.

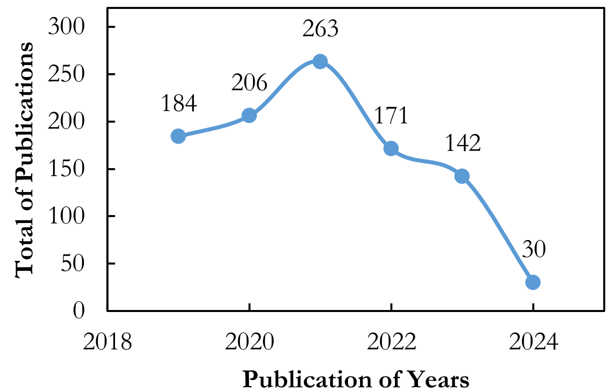

Figure 1 Annual report of publications

Table 2 Annual report research on "Project-Based Assessment on Conceptual Understanding in STEM Education"

Year	Documents	Percentages (%)
2019	184	18.47%
2020	206	20.68%
2021	263	26.41%
2022	171	17.17%
2023	142	14.26%
2024	30	3.01%
Total	996	100%

3.2 Project-Based Assessment on Conceptual Understanding in STEM Education 2019-2024

Table 3 meticulously outlines the most cited articles on Project-Based Asse ssment in STEM Education from 2019 to 2024, providing a clear picture of the topics that have garnered significant scholarly attention and impact during

Table 3 Most cited articles on project-based assessment and conceptual understanding in STEM education

No	Cites	Title	Year	Cites Per-Year	Ref.
1	1085	A review of project-based learning in higher education: Student outcomes and measures	2020	271.25	Guo et al. (2020)
2	960	Teachers' perception of STEM integration and education: A systematic literature review	2019	192	Margot & Kettler (2019)
3	444	Developing student 21st Century skills in selected exemplary inclusive STEM high schools	2019	88.8	Stehle & Peters (2019)
4	392	Examining science education in ChatGPT: An exploratory study of generative artificial intelligence	2023	392	Cooper (2023)
5	320	The effect of authentic project-based learning on attitudes and career aspirations in STEM	2019	64	Beier et al. (2019)
6	304	Problematizing teaching and learning mathematics as "given" in STEM education	2019	60.8	Li & Schoenfeld (2019)
7	261	Forms of implementation and challenges of PBL in engineering education: a review of literature	2021	87	Chen et al. (2021)
8	240	Evidence of STEM enactment effectiveness in Asian student learning outcomes	2020	60	Wahono et al. (2020)

Table 3 Most cited articles on project-based assessment and conceptual understanding in STEM education (*Continued*)

No	Cites	Title	Year	Cites Per-Year	Ref.
9	240	Design and design thinking in STEM education	2019	48	Li et al. (2019)
10	236	Active learning in engineering education. A review of fundamentals, best practices, and experiences	2019	47.2	Hernández-de-Menéndez & Vallejo (2019)
11	203	Enhancing Students' Creativity through STEM Project-Based Learning.	2019	40.6	Hanif et al. (2019)
12	201	The effectiveness of stem-based on gender differences: The impact of physics concept understanding	2019	40.2	Sagala et al. (2019)
13	196	Reviewing assessment of student learning in interdisciplinary STEM education	2020	49	Gao et al. (2020)
14	178	Computational Thinking from a Disciplinary Perspective: Integrating Computational Thinking in K-12 science, technology, engineering, and Mathematics Education	2020	44.5	Lee et al. (2020)
15	170	STEM education to fulfil the 21st century demand: a literature review	2019	34	Rifandi & Rahmi (2019)
16	169	Students' engagement in different STEM learning environments: Integrated STEM education as promising practice?	2019	33.8	Struyf et al. (2019)
17	165	Creating Manipulatives: Improving Students' Creativity through Project-Based Learning.	2019	33	Ummah et al. (2019)
18	155	Understanding K-12 STEM education: A framework for developing STEM literacy	2020	38.75	Falloon et al. (2020)
19	151	Effects of infusing the engineering design process into STEM project-based learning to develop pre-service technology teachers' engineering design thinking	2021	50.33	Lin et al. (2021)
20	150	Putting PjBL to the test: The impact of project-based learning on second graders' social studies and literacy learning and motivation in low-SES school settings	2021	50	Duke et al. (2021)

this period. The table ranks these articles according to the total number of citations received, offering a unique insight into these studies' ongoing relevance and influence in the academic community.

At the top of the list is Gao et al. (2020), whose work on project-based learning in higher education has amassed an impressive 1,085 citations, translating to an average of 271.25 citations per year. This indicates high interest and utility in understanding student outcomes and measures in project-based learning settings. The study employs various assessment instruments, including surveys and performance tasks, to evaluate student learning outcomes, demonstrating the effectiveness of PBAs in enhancing conceptual understanding.

Following closely is Margot and Kettler (2019) with 960 citations, averaging 192 per year, highlighting teachers' critical perspective on STEM integration and its systematic review. This article's high citation rate underscores the importance of teacher perceptions in the successful implementation of STEM education strategies. It utilizes qualitative assessment tools, such as interviews and focus groups, to gather insights from educators about their experiences with PBAs.

Further down the list, articles by Lin et al. (2021) and Duke et al. (2021) provide deeper insights into specialized applications of project-based learning (PjBL) and the broad implications of these methods in diverse educational contexts. Lin et al. (2021) explore the "Effects of infusing the engineering design process into STEM project-based learning to develop pre-service technology teachers' engineering design thinking," attracting 151 citations and averaging 50.33 citations per year. This study highlights the integration of engineering principles into teacher education, emphasizing the importance of preparing educators who are capable of imparting complex STEM concepts through innovative teaching strategies. The research employs rubrics and observational assessments to evaluate student learning outcomes effectively.

On a different note, Duke et al. (2021) assess "Putting PjBL to the test: The impact of project-based learning on second graders' social studies and literacy learning and motivation in low-SES school settings," which has garnered 150 citations, averaging 50 citations per year since its publication. This article investigates the effectiveness of PjBL beyond the traditional STEM subjects, extending into the realms of social studies and literacy. By focusing on second graders in low socio-economic status (SES) settings, this study provides critical insights into how PjBL can enhance motivation and learning outcomes in a demographic that might not typically receive such

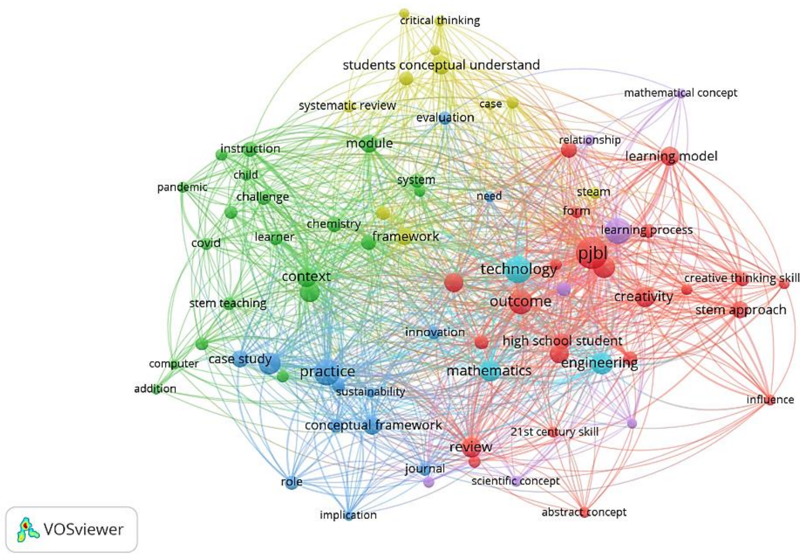

Figure 2 Network visualization based on co-occurrence of terms

innovative educational interventions. The researchers employed a mixed-methods approach, utilizing both quantitative assessments (e.g., standardized tests) and qualitative feedback (e.g., student reflections) to evaluate the impact of PBAs.

The diversity of topics and the substantial citation numbers reflect a robust engagement with various aspects of project-based learning and STEM education, highlighting critical areas such as pedagogical innovation, technology integration, and educational outcomes. These articles contribute significantly to the academic discourse and influence practical approaches in educational settings, guiding future research and implementation strategies in STEM education.

3.3 Visualization of Research Data Mapping of Project-Based Assessment on Conceptual Understanding in STEM Education

The analysis was supported by VOSviewer, a tool used to manage and analyze large sets of bibliometric data. From an initial set of 4,173 terms identified across the articles, 129 met a set threshold of occurring at least 10 times, ensuring relevance and significance in the discussion context. Further refinement was applied by selecting 60% of these terms and narrowing them down to 77, representing the core concepts and methodologies discussed across the studies.

The visualization represents a network analysis of key concepts and themes within Project-Based Learning (PBL) and STEM education (Figure 2). This graphical representation maps out the relationships and prominence of concepts clustered around six primary nodes. Each cluster represents a group of interrelated terms that collectively highlight significant areas of focus within the research on conceptual understanding in STEM education through project-based assessments.

- Cluster 1 (Red) - 23 items: This cluster concentrates on the pedagogical and outcome-based aspects of STEM education, with items like "21st-century skill," "abstract concept," "achievement," "creative thinking skill," "creativity," "critical thinking skill," "effectiveness," "elementary school," "example," "fact," "form," "high school student," "Indonesia," "influence," "learning model," "motivation," "outcome," "PjBL," "review," "science process skill," and "stem approach." These terms suggest focusing on educational strategies that enhance analytical and problem-solving skills.
- Cluster 2 (Green) - 20 items: Emphasizing contextual influences on STEM education, this cluster includes items such as "active learning," "addition," "article," "challenge," "chemistry," "child," "classroom," "computer," "context," "covid," "hand," "instruction," "learner," "module," "opportunity," "order," "pandemic," "stem teaching," "system," and "year." These terms indicate research into how factors like global events impact teaching methods and learning environments.
- Cluster 3 (Blue) - 13 items: This cluster likely explores structural and theoretical components with items including "case study," "conceptual framework," "evaluation," "implication," "innovation," "integrated stem education," "journal," "need," "pedagogy," "practice," "program," "role," and "sustainability." It highlights strategies for integrating STEM education into broader educational practices.
- Cluster 4 (Yellow) - 11 items: Focused on the evaluative aspects of STEM education, this cluster

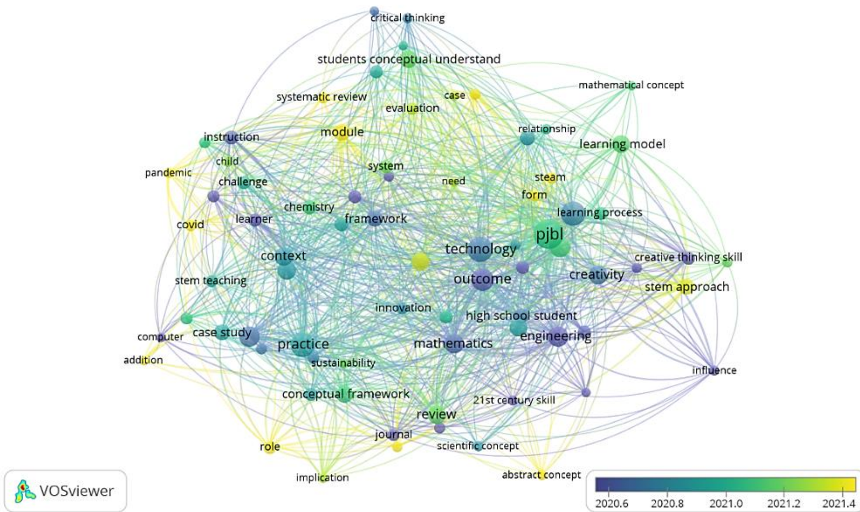

Figure 3 Overlay visualization based on co-occurrence of terms

contains items such as "case," "collaborative learning," "critical thinking," "discipline," "framework," "higher education," "paper," "steam," "students conceptual understanding," "systematic literature review," and "systematic review." These terms highlight the importance of reviews and analyses in assessing educational methodologies.

- Cluster 5 (Purple)—7 items: This cluster highlights fundamental concepts, including "ability," "basic concept," "exploration," "mathematical concept," "relationship," "scientific concept," and "theory." This cluster emphasizes the essential principles that underpin scientific and mathematical education.
- Cluster 6 (Light Blue)—3 items: This cluster represents the core disciplines of STEM—science, technology, engineering, and mathematics—and includes "engineering," "mathematics," and "technology." It focuses on the specific content areas within the broader field of STEM education.

Each cluster illustrates different facets of project-based learning in STEM, from methodological approaches and educational outcomes to the contextual and foundational theories that inform teaching practices and curriculum development.

Figure 3 is an overlay visualization based on the co-occurrence of terms related to Project-Based Learning (PBL) and STEM education. It highlights the temporal dynamics of research interests from mid-2020 to late 2021. The colors from yellow to blue represent the timeline, with yellow indicating earlier periods (around mid-2020) and blue denoting more recent discussions (towards the end of 2021). This visualization helps to identify how certain concepts have evolved within the academic discourse on STEM education.

Key observations from the visualization include:

- Recent Focus Areas (Blue Zones): Topics such as "creative thinking skill," "stem approach," and "engineering" are highlighted in blue, suggesting that these areas have gained considerable attention in recent discussions. This could indicate shifts in educational priorities or emerging trends in STEM education research, emphasizing innovation and applied learning methodologies.
- Established Concepts (Yellow to Green Zones): Terms like "module," "systematic review," and "case study" appear in yellow or green, implying that these were common topics of discussion earlier in the timeline. These foundational aspects likely set the stage for more nuanced investigations into how specific educational frameworks or methods impact learning outcomes.
- Interdisciplinary Connections: The visualization shows dense interconnections among various clusters, reflecting the interdisciplinary nature of STEM education research. For instance, the linkages between "technology," "outcome," and "21st-century skill" underscore the integrated approach that characterizes contemporary educational strategies.
- Impact of Global Events: Terms such as "COVID" and "pandemic" are also prominent, likely reflecting research into the impact of global health crises on education systems. This aligns with the green and yellow hues, indicating ongoing discussions throughout the period under review.

Overall, this overlay visualization serves as a dynamic map of research trends, showing how topics related to STEM education have developed and interacted over a specific period, and highlighting the rapid evolution of educational research in response to global challenges and technological advancements.

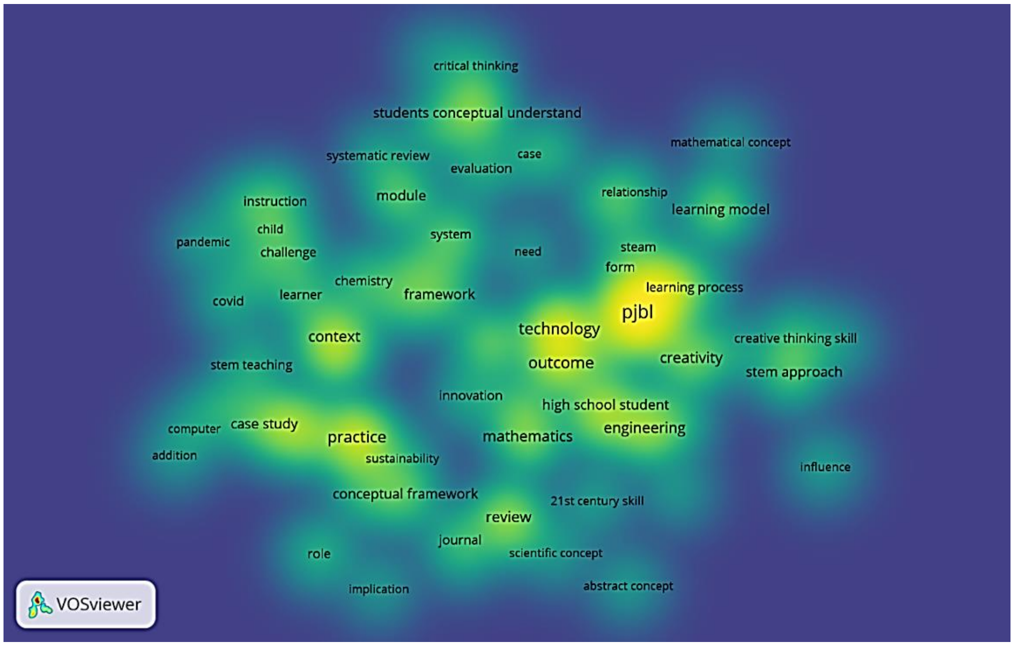

Figure 4 Density visualization based on co-occurrence of terms

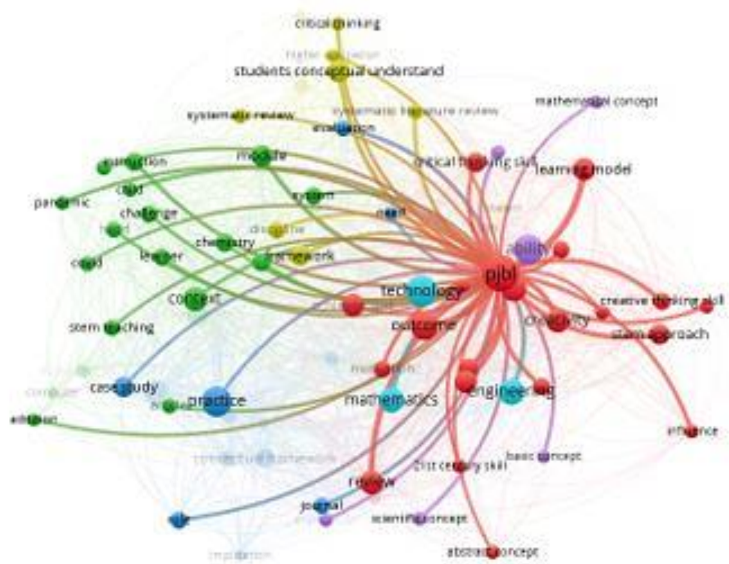

Figure 5 Network visualization of PjBL

Figure 4 presents a density visualization mapping the co-occurrence of terms within the scope of Project-Based Learning (PBL) and STEM education, employing a gradient color scheme that underscores the intensity of the research focus. The visualization uses a color range from green through blue to yellow, where greener areas signify topics with sparser research activity, and bluer zones indicate moderately explored themes. Significantly, the brightest yellow areas, such as around the term "PjBL," denote topics that have been extensively researched, suggesting a deep and well-established body of knowledge. In contrast, darker yellow regions suggest emerging areas of interest that have yet to be as thoroughly explored. Terms like "technology," "outcome," and "creativity" are highlighted in bright yellow, indicating they are central to current discussions on enhancing STEM education through innovative and technology-integrated methods. These core topics are surrounded by terms like "engineering," "21st-century skill," and "learning model," also in lighter yellow, pointing to their growing relevance in recent scholarly discussions. Meanwhile, greener zones host terms like "abstract concept" and "scientific concept," suggesting these foundational areas may require more academic attention to deepen the understanding within the field. This visualization effectively illustrates the varying degrees of research concentration across different concepts in STEM education, providing a clear indication of both well-trodden and less explored academic territories.

Figure 5 showcases a network visualization centered on Project-based Learning (PjBL) within STEM education,

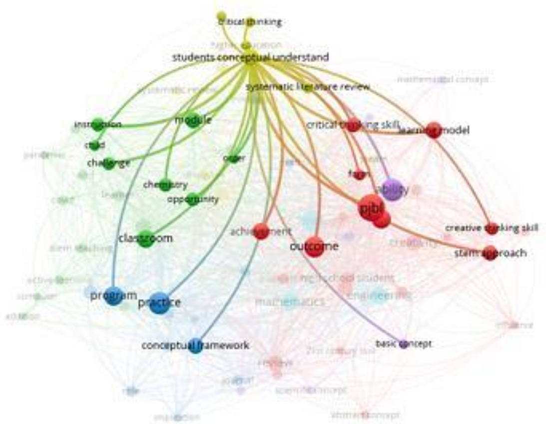

Figure 6 Network visualization of student conceptual understanding

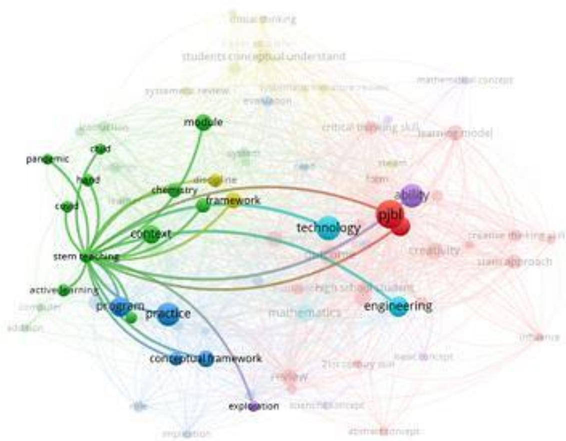

Figure 7 Network visualization of stem teaching

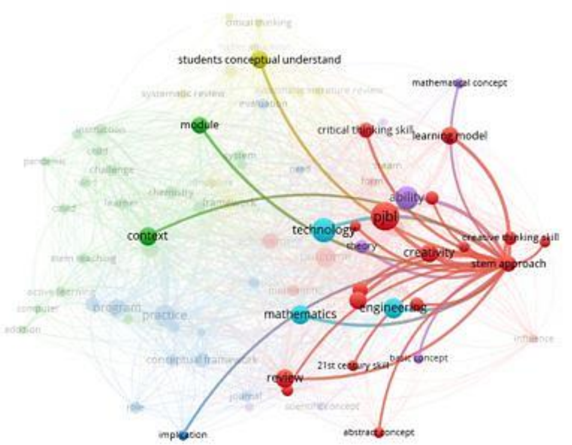

Figure 8 Network visualization of stem approach

highlighting the intricate web of concepts tied to this educational approach through a color-coded scheme representing different thematic clusters. At the heart of this visualization is the term "PjBL," colored in red to denote its central importance; it links diverse educational and pedagogical elements, such as teaching methods, learning outcomes, and curriculum design. Surrounding this central node are clusters indicating strong connections between technological applications and student outcomes in fields like engineering, and adjacent, in yellow, a cluster emphasizing pedagogical techniques that foster critical thinking and creativity. Further out, green and blue nodes represent the theoretical and contextual foundations that place PjBL within broader educational paradigms, emphasizing sustainability and systematic approaches. This visualization highlights the central role of PjBL and its interdisciplinary nature and foundational impact on various aspects of STEM education, illustrating these concepts' dynamic interplay and influence within the educational landscape.

Figure 6 displays a network visualization focused on student conceptual understanding within STEM education and project-based learning (PjBL) context. Central to the visualization, highlighted in green, is "student conceptual understanding," which serves as a pivotal node connecting various educational strategies and pedagogical concepts. Surrounding this are clusters in red and orange, emphasizing the role of PjBL, creativity, and STEM approaches in enhancing learning outcomes. Yellow nodes further explore critical pedagogical techniques such as critical thinking skills and 21st-century skills, vital for fostering a profound conceptual grasp. Theoretical and broader academic terms like "conceptual framework" and "systematic literature review," shown in blue, indicate educational research's foundational and evaluative aspects that support these practices. This network effectively illustrates the complex interplay of practical, pedagogical, and theoretical elements contributing to student conceptual understanding in STEM fields.

The network visualization highlights the interrelated concepts surrounding STEM teaching, demonstrating the central role of technology and PjBL (Project-Based Learning) in shaping modern educational strategies within the STEM fields (Figure 7). The central node, depicted in red and labeled "technology," connects directly to other vital components such as "engineering," "mathematics," and "PjBL," reflecting the integral part that technological advancements play in these disciplines. Green lines radiate from "technology" to "STEM teaching," "practice," and "conceptual framework," indicating the practical application of these technologies in educational settings and their incorporation into curricular frameworks. This visual map underscores the interconnectedness of technical skills, pedagogical methods, and curriculum design in STEM education, emphasizing the importance of integrating technology to enhance teaching effectiveness and student learning outcomes.

This network visualization delineates the interconnected themes central to the STEM approach in educational settings, with a significant focus on technology, as indicated by its central red node (Figure 8). Key connections emanate from technology to pivotal concepts such as "engineering," "mathematics," and "PjBL" (Project-Based Learning), underscoring the role of technological integration in enhancing these disciplines. The dense network of lines connecting "technology" with "creativity," "21st-century skill," and "critical thinking skill" highlights the drive towards fostering innovative and analytical skills in students. This configuration emphasizes the holistic nature of the STEM approach, which integrates different scientific disciplines and interlinks them with essential skills and pedagogical strategies, promoting a comprehensive and interconnected educational framework to prepare students for future challenges.

4. DISCUSSION

The recent research documented in "A Bibliometric Analysis of the Impact of Project-Based Assessment on Conceptual Understanding in STEM Education" significantly contributes to our understanding of project-based learning (PBL) methodologies. Project-based learning, especially in the context of STEM education, facilitates an integrative learning environment where students can engage deeply with real-world problems, enhancing both their cognitive and collaborative skills (Fang et al., 2021). As the data and subsequent analysis show, there has been a considerable fluctuation in the number of publications from 2019 to 2024, reflecting a dynamic shift in research outputs, which could be attributed to various factors, including the changing educational demands triggered by global events such as the COVID-19 pandemic.

This period of increased academic activity notably peaks in 2021, perhaps driven by a heightened demand for innovative teaching methodologies during the pandemic. The analysis from this peak period has shown that PBL supports the integration of different STEM disciplines and significantly enhances students' conceptual understanding and critical thinking, thus making STEM fields more accessible and appealing (Yabas et al., 2022). This is particularly evident in how students are prepared to face complex real-world problems, potentially leading to an increased confidence in pursuing STEM careers (Mustafa et al., 2016). Furthermore, the decline in publications post-2021 might suggest a phase of refining and implementing the developed methodologies rather than exploring new conceptual grounds.

Moreover, the implementation of PBL has shown to enhance teacher effectiveness in delivering innovative instructions, which in turn benefits student learning outcomes (Siew et al., 2015). This reiterates the importance of project-based learning in fostering student engagement and learning and enhancing pedagogical methods. Additionally, the use of technology, such as 3D printing in PBL, further supports this by enabling a hands-on approach to understanding complex concepts and processes, especially in engineering education (Lin et al., 2018).

Overall, the data supports the efficacy of project-based learning as a critical educational approach in STEM fields, underscoring its role in enhancing conceptual understanding and preparing both students and teachers to meet the challenges of modern educational demands. The sustained interest and application of PBL suggest its foundational importance in the evolution of teaching strategies within the STEM disciplines. The shift towards more active and integrated learning environments, as highlighted by these findings, offers significant implications for educational practices and policies aimed at fostering a more robust and interdisciplinary approach to STEM education.

5. CONCLUSION

The exploration conducted in "A Bibliometric Analysis of the Impact of Project-Based Assessment on Conceptual Understanding in STEM Education" profoundly illustrates project-based learning (PBL) 's significant role in enhancing conceptual understanding within STEM education. As the findings from 2019 to 2024 demonstrate, there is a notable fluctuation in research outputs, highlighting a dynamic evolution in educational methodologies driven by shifting academic and practical needs. The peak in research activity in 2021, catalyzed by the urgent demand for innovative educational approaches during the COVID-19 pandemic, emphasizes PBL's effectiveness in integrating STEM disciplines, enhancing students' problem-solving capabilities, and preparing them for real-world challenges.

Moreover, this research underscores the importance of project-based learning in boosting student engagement and learning outcomes and enhancing pedagogical practices. Through PBL, teachers are better equipped to deliver innovative instruction that goes beyond traditional teaching methods, fostering an educational environment that encourages critical thinking, creativity, and active learning. This approach is further supported by the integration of modern technologies such as 3D printing, which enriches the learning experience by providing more tangible, hands-on interactions with complex STEM concepts.

In conclusion, project-based learning stands as a cornerstone in the ongoing transformation of STEM education. By continuously incorporating PBL strategies into educational frameworks, educators can ensure that teaching practices keep pace with technological advancements and align with the evolving demands of the global workforce. The sustained interest in PBL across various studies highlights its vital role in advancing educational outcomes and paves the way for future research to optimize these methodologies, ensuring that they remain robust, effective, and inclusive for all learners.

This comprehensive review provides a strategic roadmap for educators, policymakers, and researchers, offering insights and evidence-based recommendations that will help to further invigorate STEM education globally.

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