

## **Project-Based Learning-Science, Technology, Engineering, and Mathematics (PjBL-STEM): A Bibliometric Mapping of Themes and Research Gaps**

Submitted 28 February 2026, Revised 28 March 2026, Accepted 28 March 2026

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This study aimed to examine the integration of Project-Based Learning (PjBL) in STEM education and identify research gaps. This study uses a bibliometric approach by analyzing 102 Scopus-indexed articles from 2014–2025. The analysis shows a significant increase in publications related to PjBL-STEM. Thematically, PjBL and STEM are interconnected core topics and form several research clusters, with the thinking skills cluster being the most central theme connected to issues of sustainable education and digital learning. Furthermore, keywords related to 21st-century competencies, such as critical and creative thinking, are more dominant than digital technologies, such as e-learning, artificial intelligence, machine learning, and learning analytics, which have not yet taken center stage in the research landscape. These findings indicate a gap in the integration of digital technologies in PjBL-STEM learning. Therefore, further research is recommended to focus on: (1) developing a digital technology-based PjBL-STEM model, (2) integrating learning analytics to monitor the learning process, and (3) strengthening data-based formative assessment to support 21st century skills.

Keywords: Artificial Intelligence, Learning Analytics, Project-Based Learning, Smart Teaching, STEM Education.

### **INTRODUCTION**

Project-Based Learning (PjBL) has been shown to support learning through investigative activities, experiments, and artifact creation in response to real-world problems in a contextual manner (Fatimah Sham Ismail et al., 2023; Aishwarya M et al., 2024; Zhang, Guan, and Hu, 2024). The integration of Science, Technology, Engineering, and Mathematics (STEM) strengthens PjBL by connecting science concepts, engineering practices, and technology utilization, so that projects not only produce products but also develop scientific reasoning and problem-solving skills (Purwaningsih et al., 2020; Ahmada, Suwono, and Fachrunnisa, 2021; Fitriani et al., 2025; Pinar et al., 2025; Syamra and Suryadi, 2025). Digital transformation also encourages the use of learning platforms and learning management systems to manage projects, collaboration, and documentation (Velinov and Bleicher, 2023; Ntunka et al., 2024; Bhagwat and Kulkarni, 2025), thereby strengthening digital support in the implementation of PjBL-STEM.

Furthermore, in recent years, e-learning, artificial intelligence (AI), machine learning, and learning analytics have been leveraged to integrate progress, accelerate feedback, and support data-driven decision-making throughout the learning process (Nazaretsky et al., 2022; Fernández Jiménez, 2024; Mittal et al., 2024). The use of learning data to support pedagogical

decisions through monitoring, feedback, and formative assessment is a key characteristic of intelligent teaching. Thus, intelligent teaching has the potential to strengthen PjBL-STEM in science learning through a more adaptive and scalable approach, particularly through technology that supports continuous monitoring, science practices, and assessment throughout the learning process.

Currently, numerous publications on PjBL-STEM have been found (Sager, Milton, and Walkington, 2025; Sukarno et al., 2025; Chen and Lin, 2026; Xie, Wan, and Kong, 2026). However, based on the literature presented above, it is still dominated by implementation studies and reviews that focus on learning outcomes. Consequently, a conceptual understanding of the role of intelligent teaching technologies in PjBL-STEM has not yet been systematically developed. This is evident in the lack of a mapping that explicitly places e-learning, artificial intelligence, machine learning, and learning analytics within the PjBL-STEM research framework, particularly regarding their roles in process monitoring, feedback mechanisms, and data-driven formative assessment. Furthermore, studies on intelligent teaching technologies remain fragmented, with limited integration of learning analytics to support real-time project management and monitoring, ongoing assessment, and data-driven decision-making in pedagogical design.

Given the limitations of conceptual synthesis and the fragmented nature of learning technology studies in PjBL-STEM research, this study conducted bibliometric mapping to uncover the thematic structure, core themes, connecting themes, and the dynamics of topic evolution within the PjBL-STEM landscape. Through keyword co-occurrence analysis and thematic maps, this study examined the position of intelligent teaching technologies, specifically artificial intelligence and learning analytics, within PjBL-STEM research. The findings of this mapping are expected to serve as a basis for formulating research agenda priorities and guiding the selection of relevant technologies to strengthen science practices and data-driven formative assessment in science learning.

Therefore, to answer the research objectives and identified gaps, this study is formulated in several research questions as follows; RQ1: What is the trend of PjBL-STEM research publications in the period 2014–2025?, RQ2: What is the structure of PjBL-STEM research themes and clusters based on keyword co-occurrence analysis?, RQ3: What is the position of learning technology as a supporter in PjBL-STEM research in terms of the role of core themes and connecting themes in the keyword network?, RQ4: What are the research gaps related to strengthening the digital ecosystem, especially artificial intelligence and

learning analytics, to support project management and monitoring and formative assessment in science learning?

## **METHOD**

### **Research design**

This study used a quantitative bibliometric study to map publication trends and the conceptual structure of PjBL–STEM research, and to examine the position of technology themes within the smart teaching framework.

### **Data source, time span, search strategy, and dataset profile**

Bibliographic data were retrieved from the Scopus database for the period 2014–2025. The search was conducted in the TITLE-ABS-KEY fields using the query: "STEM project-based learning" OR "STEM-PjBL" OR ("STEM education" AND "project-based learning"). The search results were exported as a CSV file, then filtered for relevance and duplicates removed to yield a final dataset of 102 documents from 56 sources. The dataset contains 307 authors' keywords (DE) and 104 Keywords Plus (ID), with an average of 16.64 citations per document.

### **Data Cleaning and Keyword Harmonization (OpenRefine)**

The exported Scopus files were cleaned using OpenRefine to ensure metadata consistency, particularly in the keyword column. The cleaning process included standardizing spelling and formatting, unifying term variations (e.g., "project-based learning" and "project-based learning"), merging synonyms with their more precise equivalents, and removing uninformative generic terms. The cleaned dataset was then re-exported for subsequent analysis.

### **Analysis Procedures (RStudio)**

The analysis was carried out in two stages. First, performance analysis was employed to demonstrate publication trends and citation indicators. Subsequently, the conceptual structure was examined through a keyword co-occurrence-based co-word network with association strength normalization and clustering using the Louvain algorithm. The analysis of the role of themes was carried out through network metrics such as betweenness centrality, closeness centrality, and PageRank centrality. This was done to identify core and connecting themes. The thematic map was employed to identify the type of themes—motor, basic, niche, and emerging/declining themes. The interpretation of the results was carried out by analyzing the position of AI and LA in the PjBL-STEM ecosystem.

### **Operational Definition of Smart Teaching**

In this study, smart teaching is defined as the adaptive, data-driven orchestration of project-based learning using technology to monitor processes, provide timely feedback, and strengthen formative assessment. Operationally, smart teaching indicators are explored through the emergence and interconnectedness of themes such as artificial intelligence/machine learning and learning analytics (including themes that overlap with process monitoring, feedback, and data-driven formative assessment).

### **Software, Packages, and Parameter Settings**

Preprocessing was performed using OpenRefine, while bibliometric and network analyses were conducted in R using RStudio. Bibliometric analysis and theme mapping were executed using the bibliometrix package. At the same time, network computations and centrality metrics were calculated using igraph, with support for tidyverse and stringr for text structuring and normalization. The network was constructed as an undirected, weighted graph using a full-counting scheme for keyword co-occurrence. To maintain map stability and readability, very low-frequency terms were filtered using a minimum frequency threshold; the process, which involved random initialization, was controlled through the seed setting in the R script.

### **Output and reporting**

The analysis outputs include a summary of performance indicators, a co-word network map, thematic cluster results, core and connecting node metrics, and a thematic map, which serve as the basis for reporting results and discussing the answers to research questions.

## **RESULTS AND DISCUSSION**

As a basis for bibliometric analysis to answer the research questions, Table 1 presents the general characteristics of the PjBL-STEM publications analyzed in this study. The data includes 102 articles from 56 Scopus-indexed sources for the period 2014–2025. Quantitatively, the annual publication growth rate reached 34.93%, with an average document age of 3.46 years and an average citation rate of 16.64 citations per document. These findings indicate that PjBL-STEM research is growing rapidly and is receiving a high level of academic attention. In terms of content, there are 307 author keywords and 104 additional keywords, reflecting the diversity and complexity of thematic focus. In terms of collaboration, an average of 3.91 authors per document and 21.57% international collaborations indicate a fairly strong collaborative network within the research community. Overall, these findings provide a basis for mapping thematic structures, identifying research gaps, and understanding the direction of PjBL-STEM research development.

Table 1. General characteristics of PjBL–STEM research data for the period 2014–2025

Description	Results
<b>Main Information About Data</b>	
Timespan	2014:2025
Sources (Journals, Books, etc)	56
Documents	102
Annual Growth Rate %	34.93
Document Average Age	3.46
Average citations per doc	16.64
References	913
<b>Document Contents</b>	
Keywords Plus (ID)	104
Author's Keywords (DE)	307
<b>AUTHORS</b>	
Authors	366
Authors of single-authored docs	5
<b>Authors Collaboration</b>	
Single-authored docs	5
Co-Authors per Doc	3.91
International co-authorships %	21.57
<b>Document Types</b>	
article	102

### Trends in PjBL–STEM Research Publications

This section analyzes the growth dynamics of scientific publications related to PjBL–STEM during the period 2014–2025 (see Figure 1).

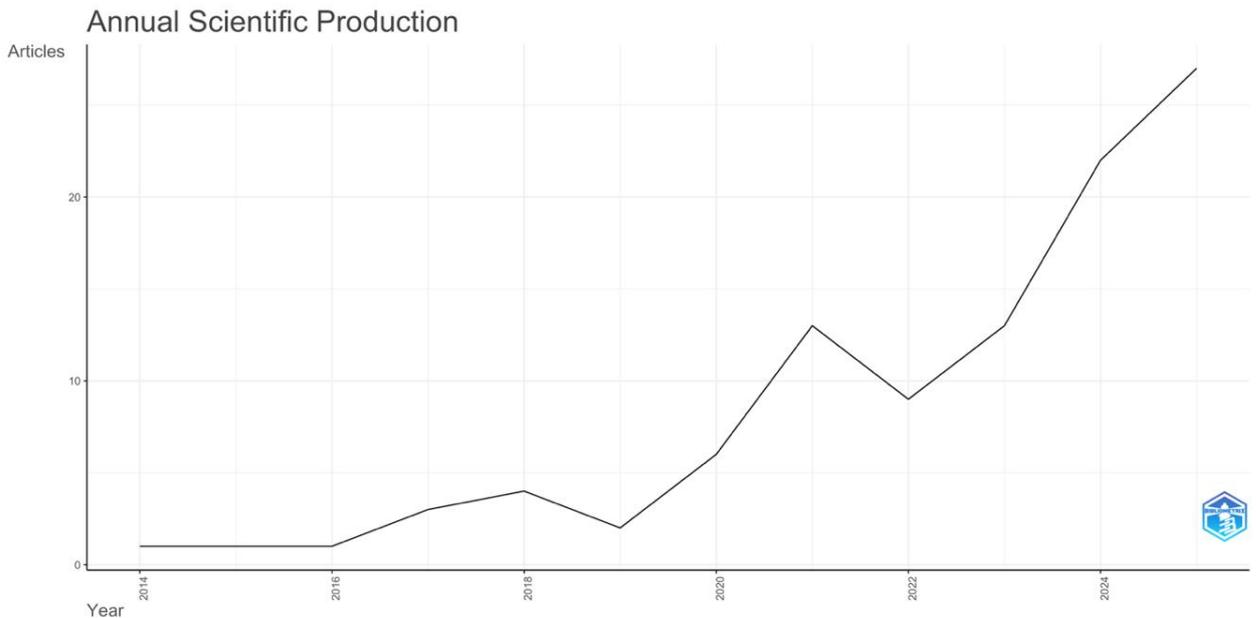


Figure 1. PjBL–STEM research publication trends 2014–2025

Figure 1, a bibliometric analysis shows that PjBL–STEM publication production increased significantly between 2014 and 2025. In the initial phase 2014–2016, the number of publications was still limited, at around 1–2 articles per year. The increase began to be seen in

2017 and accelerated after 2020. The peak productivity occurred in 2025 with more than 20 articles. These findings indicate that PjBL–STEM is increasingly becoming a focus of attention in educational research. This increase aligns with the demands of 21st-century learning, the strengthening of science and technology integration, and the acceleration of digital transformation (Baran et al., 2021; Sumarni et al., 2023; Retno et al., 2025). In addition, various studies report the effectiveness of PjBL-STEM in developing creativity, critical thinking, and problem-solving skills (Baran et al., 2021; Adikayanti and Retnawati, 2022; Syamra and Suryadi, 2025).

However, the results of the thematic mapping indicate that most research still focuses on learning outcomes. Studies that explicitly explore the development and interrelationship of technology themes with pedagogical design and assessment are still relatively limited. However, from an intelligent teaching perspective, the use of learning data for process monitoring, feedback, and formative assessment is a crucial component. Therefore, mapping thematic structures is important for a more comprehensive understanding of the position and role of technology in the PjBL-STEM research landscape.

### **PjBL–STEM Topic and Research Cluster Map**

This section maps the main topics and research clusters of PjBL-STEM based on the relationships between keywords. Analysis was conducted using keyword co-occurrence networks and thematic maps to identify core themes, connecting themes, and themes with potential for development.

#### ***Keyword Interrelationship Map (Co-word Network)***

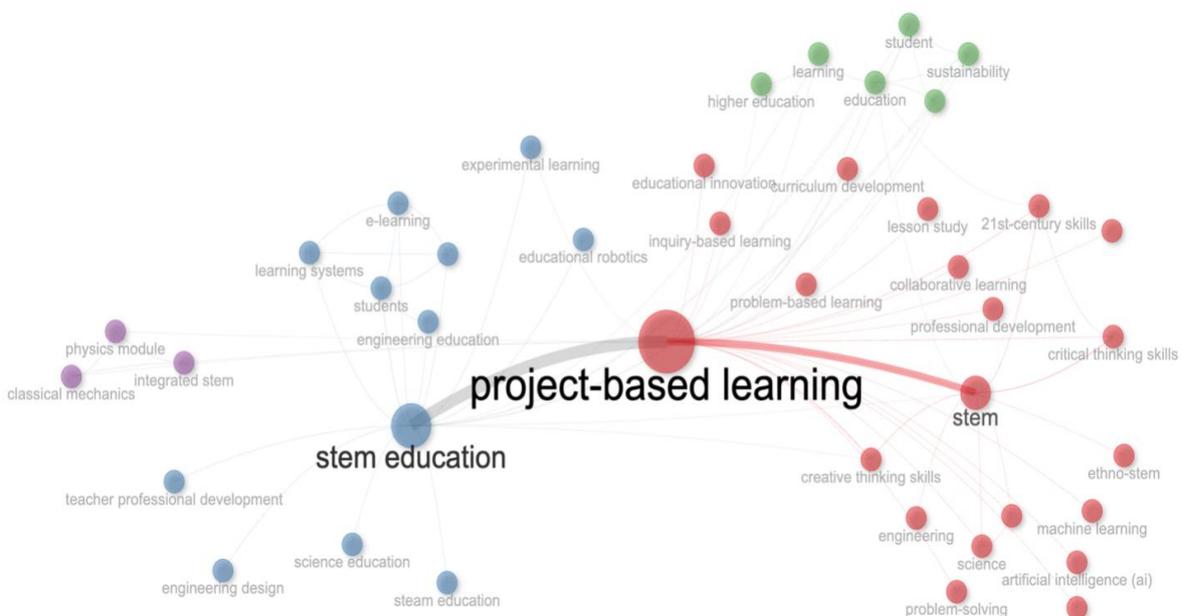


Figure 2. Co-Word network map of PjBL–STEM research keywords for the 2014–2025 period

The network map results in Figure 2 indicates that PjBL is a core node closely related to STEM education and forms several key clusters. The pedagogical and competency clusters position PjBL closely with approaches such as problem-based learning, inquiry-based learning, and collaborative learning, and are related to outcomes such as creative thinking, critical thinking, and problem-solving, as well as implementation issues such as curriculum development, educational innovation, and professional development. The STEM ecosystem cluster centers on STEM education and encompasses implementation contexts such as science and engineering education, engineering design, and elements of digital learning and educational technology, including e-learning, learning systems, and educational robotics. In addition, smaller clusters related to general education and sustainability were identified, such as higher education, students, and sustainability, as well as peripheral content-based clusters such as integrated physics, classical mechanics, and STEM modules.

Overall, the keyword map indicates that the domains of pedagogy and learning outcomes still dominate the PjBL-STEM research landscape, while intelligent technologies such as artificial intelligence and machine learning are emerging but have not yet acted as a bridge between clusters. This finding aligns with previous research showing that the integration of artificial intelligence and machine learning in PjBL-STEM still tends to be positioned as supporting elements (Tabakova-Komsalova et al., 2024; Xiaonan Yu and Dong Yang, 2024; Guo, Halim, and Saad, 2025; Pramasdyahsari et al., 2024). Furthermore, the lack of a prominent assessment theme within the network suggests that the linkage of technology to assessment strategies, particularly formative and data-driven assessment processes, has not yet become a primary focus. Assessment in PjBL-STEM is still dominated by product or outcome evaluation (Pramasdyahsari et al., 2023; Sumarni, Wahyuni, and Sulhadi, 2023; Rohman et al., 2024; Sukarno et al., 2025), while explicit interaction between learning and data-driven approaches is still rare. Thus, research findings indicate limited integration between technology, pedagogical design, and assessment within a coherent PjBL-STEM framework. This gap is crucial because meaningful technology integration requires alignment between project activities, learning objectives, and assessment indicators to support monitoring and feedback processes. In line with the concept of intelligent teaching, technology should be leveraged to collect and analyze learning data to support adaptive feedback and ongoing instructional decision-making.

### PjBL–STEM Research Topic and Cluster Map (Thematic Map)

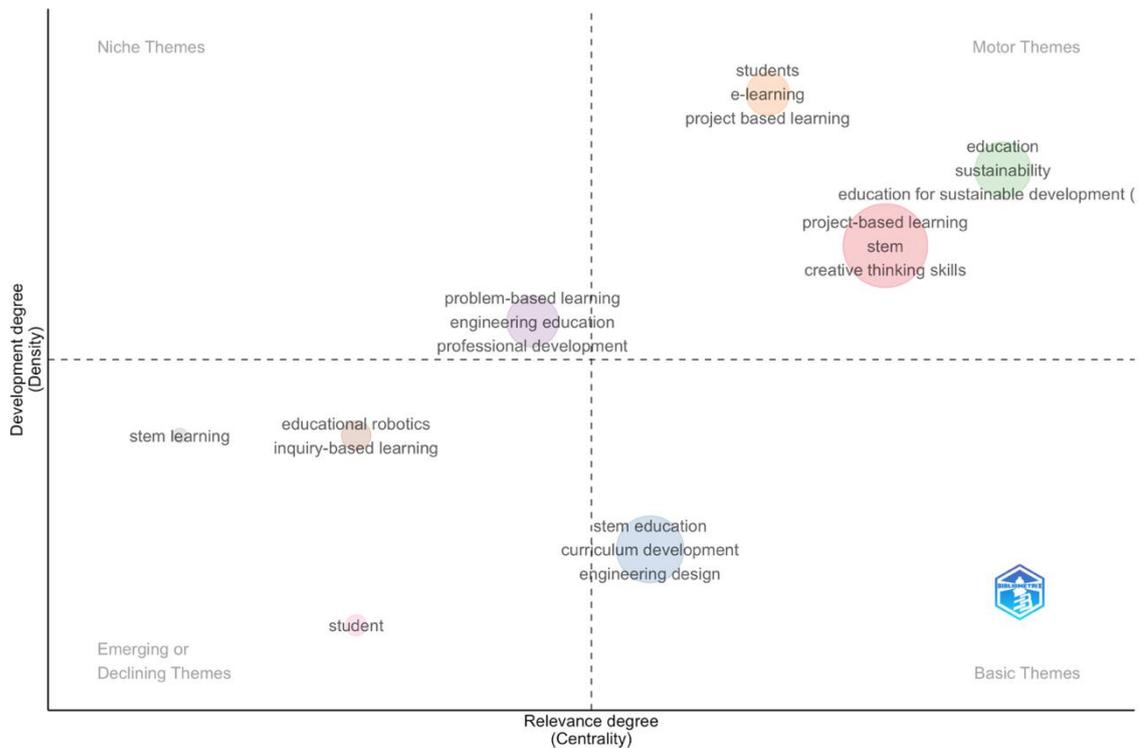


Figure 3. Thematic map of PjBL–STEM research for the 2014–2025 period

Figure 3 shows that the PjBL, STEM, and creative thinking skills clusters are located within the motoric theme, as the most central and growing theme. This theme relates to education, sustainability, education for sustainable development, students, and e-learning, indicating an expansion of the PjBL–STEM focus to sustainability issues and digital learning contexts. Within the foundational theme, STEM education, curriculum development, and engineering design emerged as key foundations in instructional design. Within the specific themes, problem-based learning, engineering education, and professional development emerged as growing but not yet dominant themes. Meanwhile, within the growing or declining themes, educational robotics, inquiry-based learning, STEM learning, and students were identified as areas with potential for strengthening.

The results of this mapping indicate a research gap in the perspective of intelligent teaching, particularly regarding the use of learning data to support the learning process. Although e-learning is beginning to approach central themes, themes explicitly representing data-driven practices, such as analytical learning and data-driven formative assessment, have not yet emerged prominently in the motor or foundational themes. This finding aligns with previous research showing that digitalization in PjBL–STEM focuses more on learning platforms and access, while the use of analytical data for formative assessment remains limited (Bezverhny et al., 2020; Fernando, 2020; David et al., 2022; Chen et al., 2023;

Rarugal and Sermona, 2024). This suggests that digitalization in PjBL–STEM research is progressing more rapidly at the platform, context, and learning ecosystem levels. Conversely, the use of data for process monitoring and pedagogical decision-making has not yet become mainstream. These findings are also supported by previous research showing that technology integration in PjBL–STEM is still oriented towards media and learning environments, with limited data-driven mechanisms for integrating collaboration, project processes, and ongoing feedback (Bakri, Budi, and Rahmawati, 2023; Pramasdyahsari et al., 2024; Sukarno et al., 2025). Therefore, technology's position in the current research landscape tends to be as a supporting tool for implementation, rather than as an integrative component connecting pedagogical design with process-based assessment. These findings provide a basis for developing a future research agenda, namely, strengthening the integration of technology, pedagogy, and assessment through the exploration of data-driven themes, such as analytical learning and digital formative assessment in the PjBL–STEM context.

### Technology as a Supporter in PjBL–STEM Studies and 21st-Century Competencies

This section maps the position of technology in PjBL–STEM research and its relationship to 21st-century competencies. In this study, intelligent teaching is defined as the use of learning data to support pedagogical decisions through monitoring, feedback, and formative assessment. Analysis was conducted using the most relevant keywords, trending topics, and a three-plane plot.

#### Most Relevant Word

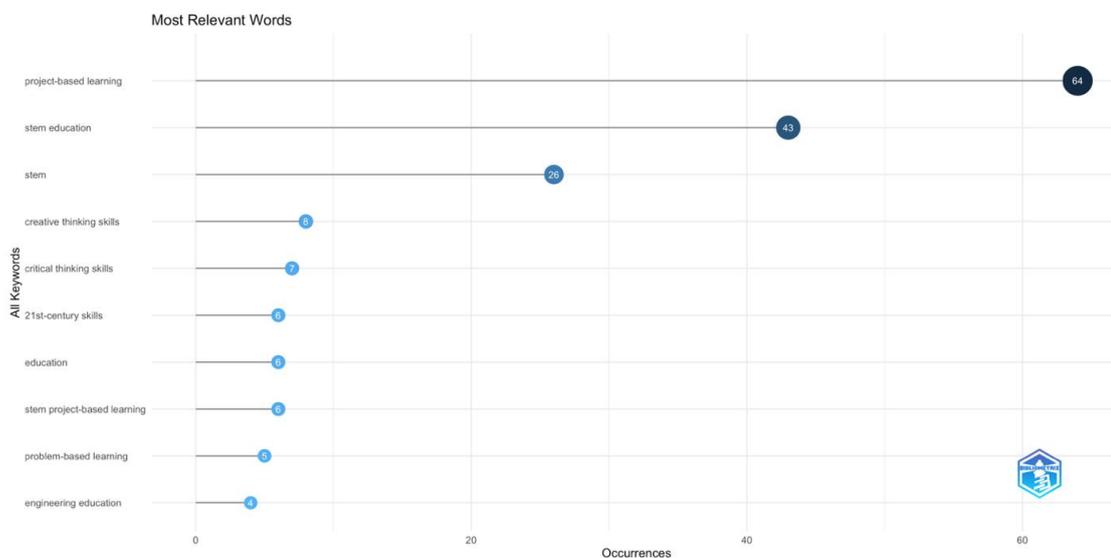


Figure 4. Distribution of the most relevant keywords in PjBL–STEM research 2014–2025

The Figure 4 shows the dominance of pedagogical themes and the context of PjBL–STEM. STEM education and PjBL emerged as the most dominant keywords. Other keywords focused on 21st-century competencies, specifically creative thinking, critical thinking, and

21st-century skills. This pattern indicates that PjBL–STEM research remains oriented toward implementing learning and achieving higher-order cognitive outcomes. Conversely, indicators of intelligent teaching have not yet emerged as dominant keywords. The terms e-learning, artificial intelligence, machine learning, and analytical learning have not appeared significantly in the top keyword list.

These findings indicate that while the literature emphasizes the potential of digital technologies and artificial intelligence to support 21st-century learning, these technologies have not been strongly integrated into the PjBL–STEM research landscape. This aligns with previous research showing that digital technologies and artificial intelligence have the potential to support personalized learning, data-driven feedback, and formative assessment, but are still limited in the PjBL–STEM context (Chang et al., 2023; del Pilar Gonzalez and Chiappe, 2024; Rauf, Deli, and Husin, 2025; Sheejamol, Chacko, and Kumar, 2025; Al Nabhani, Hamzah, and Abuhassna, 2026). Thus, at the dominant keyword level, technology in PjBL–STEM research tends to be positioned as a context or enabler of implementation. At the same time, the primary focus remains on developing 21st-century competencies as learning outcomes.

### ***Trend Topics***

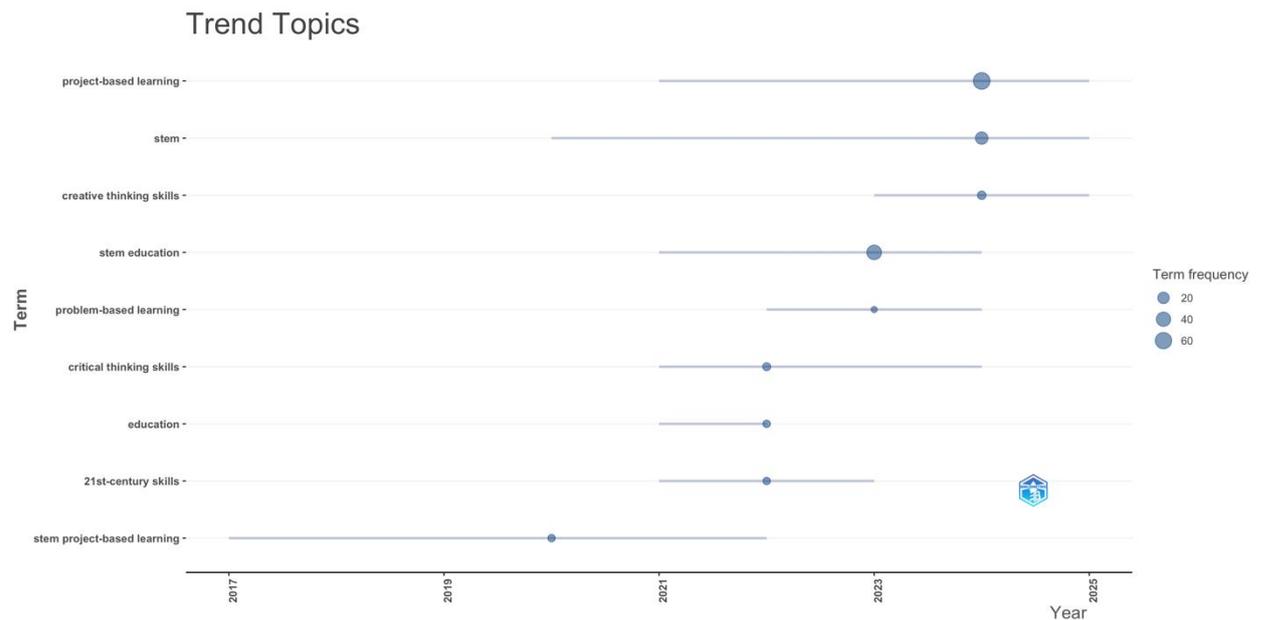


Figure 5. Trend topics in PjBL–STEM research for the 2020–2025 period



thinking and critical thinking, are also connected, but remain under the dominance of the core theme. In contrast, technology keywords such as artificial intelligence and machine learning appear with relatively weak connections.

This pattern indicates that technology has not yet become mainstream in the PjBL–STEM knowledge structure. Several previous studies have shown that technology is more often positioned as a project facilitator rather than as an integrated component in the conceptual framework. This finding is consistent with the literature reporting that technology integration in PjBL–STEM is still supportive, so its linkage to the knowledge structure and learning design has not yet been firmly established (Widarti, Rokhim, and Syafruddin, 2020; Diana, Yohannes, and Sukma, 2021; Bakri, Budi, and Rahmawati, 2023; Sukarno et al., 2025). Therefore, strengthening the more explicit integration of technology with pedagogical design and data-driven formative assessment within the PjBL–STEM framework is necessary.

### **Research Gaps and Strengthening the Digital Ecosystem in PjBL–STEM**

This section maps research gaps related to strengthening digital ecosystems and the shift towards data-driven learning in the context of PjBL–STEM. Analysis is conducted using thematic maps and factor analysis to confirm the position of e-learning, artificial intelligence, learning analytics, and data-driven formative assessment in the research landscape.

#### ***Thematic Map***

The thematic map results show that the main theme is dominated by the PjBL–STEM cluster, which strongly overlaps with competency outcomes, particularly creative thinking. Contextual themes such as sustainability and education for sustainable development also emerged as mainstream. The presence of student clusters, e-learning, and project-based learning within the main theme area indicates that digital support is beginning to be integrated into the PjBL–STEM implementation ecosystem.

However, themes explicitly representing artificial intelligence, learning analytics, and data-driven formative assessment have not yet emerged prominently within the main themes. This indicates that the process of digitalization through e-learning is taking place at a faster rate than the development of data-driven intelligent teaching methods. Moreover, previous studies also highlight the need for data-driven methods such as learning analytics to monitor the project process and facilitate timely feedback and formative assessment (Sagarika, Kandakatla, and Gulhane, 2021; Andriamiseza et al., 2023; Bulut et al., 2023; Arthars et al., 2024; Tempelaar, Rienties, and Giesbers, 2024). As such, the integration of technology into the PjBL-STEM cycle of planning, implementation, and reflection needs to be addressed as a

thematic mapping to highlight opportunities for the development of data-driven technology in PjBL-STEM learning.

### **Factorial Analysis**

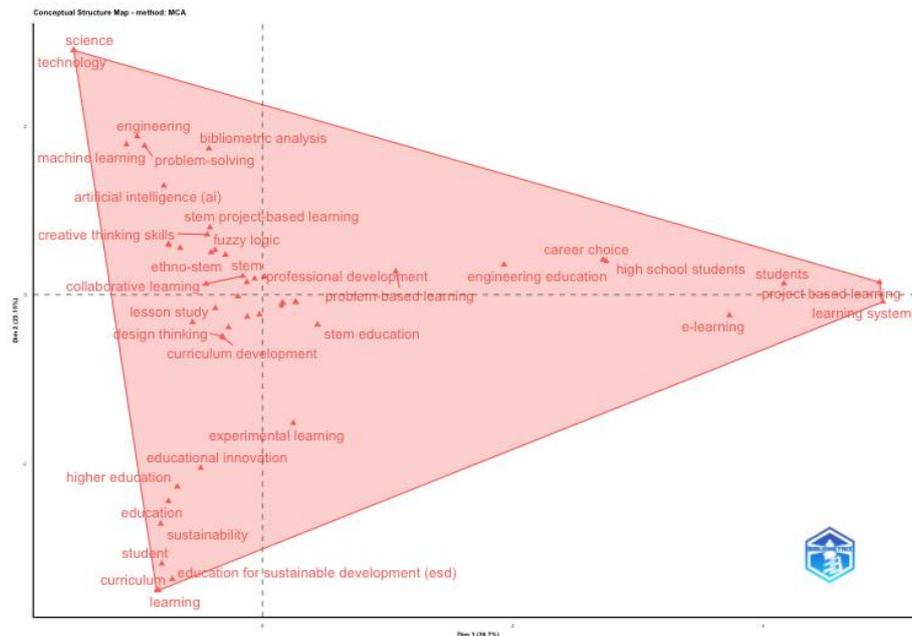


Figure 7. Conceptual structure map of PjBL–STEM research based on factorial analysis for the 2014–2025 period

Based on factor analysis in Figure 7, the conceptual structure of the PjBL–STEM literature forms several main thematic clusters. From an implementation perspective, the close relationship between PjBL and students, learning systems, and e-learning demonstrates the strengthening of the digital learning context within the PjBL–STEM ecosystem. On the other hand, the STEM cluster, oriented toward science and computational technology, groups concepts from science, technology, and engineering with artificial intelligence and machine learning, as well as outcomes such as problem-solving. Another cluster represents the educational context and aspirations by grouping education, higher education, and education for sustainable development (ESD).

This structure indicates that artificial intelligence and machine learning are primarily associated with the computing technology cluster and its outcomes. In contrast, assessment topics, including learning analytics and data-driven formative assessment, have not yet emerged prominently in the conceptual map. This finding indicates that artificial intelligence in the corpus is more often positioned as a computing technology approach rather than as a pedagogical tool for process monitoring and data-driven decision-making. This aligns with previous research showing that the application of artificial intelligence and machine learning in education is still largely directed at the development of computing applications, such as modeling, classification, and automation (Liu and Xie, 2021; Tang, Ratana-Olarn, and

Petsangsri, 2023; Eger, 2025; Jaboob, Hazaimah, and Al-Ansi, 2025; Xie and Zore, 2025). Meanwhile, the integration of these technologies with pedagogical design to support data-driven learning monitoring, feedback, and formative assessment remains relatively limited. This condition explains why the role of artificial intelligence has not been established as an integrative component in the PjBL–STEM cycle, because the linkages between artificial intelligence, learning analytics, and formative assessment are still weak in the conceptual landscape.

## **CONCLUSION**

This study maps the PjBL–STEM research landscape for the period 2014–2025 using a bibliometric approach to identify publication growth, thematic structure, and topic evolution. The results show a significant increase in publications, particularly after 2020, confirming the strengthening position of PjBL–STEM in educational research. From a thematic point of view, PjBL, STEM, and creative thinking skills have been identified as primary themes. STEM education, curriculum development, and engineering design have been identified as basic themes. The sustainability themes of education for sustainable development are becoming more important. However, other themes like educational robotics and inquiry-based learning are still marginal. From a technological point of view, the phenomenon of digitalization is dominated by e-learning and learning systems. Although artificial intelligence and machine learning are becoming important, they have not yet been identified as primary themes. In addition, data-driven intelligent approaches to teaching, like learning analytics and process-oriented formative assessment, have still not been included in the thematic structure. This underlines the research gap identified in the previous section: PjBL/STEM development progresses faster in the adoption of digital platforms than in the integration of data-driven technologies. The primary contribution of this paper is to validate this research situation and provide a future research agenda empirically. The proposed research agenda focuses on the following key priorities: (1) Integrating data-driven, intelligent teaching across all phases of PjBL, from planning and implementation to reflection on learning. (2) Developing learning analytics to support data-driven formative assessment of project processes and artifacts. (3) Designing data-driven, adaptive feedback systems to support ongoing pedagogical decision-making.

## **ACKNOWLEDGEMENT**

The authors would like to thank Muhammadiyah University of Jember, Indonesia, for the financial support provided for this research. This support played a crucial role in enabling the entire research process, including the preparation and dissemination of the study results.

#### **Availability of data and material**

The datasets generated and/or analyzed during the current study are available from the first author upon reasonable request.

#### **Funding**

Muhammadiyah University of Jember

#### **Ethics approval**

Not Applicable

#### **Patient consent statement**

Informed consent was obtained from all individual participants included in the study.

#### **Permission to reproduce material from other sources**

No material from other sources was used in this manuscript.

#### **Clinical trial registration**

This study is not a clinical trial and does not require registration.

#### **Declaration of generative AI and AI-assisted technologies in the writing process**

During the preparation of this work the author used QuillBot in order to improve the language and readability. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

#### **Credit authorship contribution statement**

Ali Usman, Selfi Maharani, Tri Asih Wahyu Hartati, Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

#### **Declaration of competing interest**

The authors declare that they have no competing financial or non-financial interests in relation to this study.

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