

## Research landscape of PBL-STEM education: a systematic analysis review

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### ABSTRACT

The science, technology, engineering, and mathematics (STEM) education has emerged as a global education priority, many countries have printed their development strategies to national blueprints and recognized STEM education as a key role in the effective implementation of skills training in the 21st-century. Project-based learning (PjBL) and problem-based learning (PrBL) or PBL is significant in cultivating students' knowledge and skills, integrating PBL into STEM (PBL-STEM) education is a new attempt in recent years to integrate student-centered learning methods into the STEM learning process. This study aims to explore the development trends of PBL-STEM and provide recommendations to support talent cultivation in the digital era. Based on a systematic review of 1999 articles in SCOPUS database, this study uses content analysis to identify key themes in PBL-STEM. The findings indicate that the construction of student-centered PBL curriculum, the development of innovative teaching models, and interdisciplinary integration are central to the evaluation of PBL-STEM. Moreover, the integration of emerging technologies and multi-disciplinary approaches enhances STEM competency to cultivate 21st-century skills. PBL-STEM emphasize students' higher-order abilities, positioning it as a strategic reform for future society. This study reveals the importance of curriculum innovation, instructional reform, evaluation mechanisms, and the professionalization of STEM educators are fundamental with the rapid technological advancement.

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## 1. INTRODUCTION

Science, technology, engineering, and mathematics or STEM education originated in the United States in the 1980s, after more than 40 years of development, more and more countries and regions have realized the importance of STEM education to talent training and national development. STEM education has also been proved to effectively improve students' ability to solve complex problems and is beneficial to students' career development [1], [2]. Many studies and policies focusing on the field of STEM education, some of which are involved with the development of education policy, some on STEM learning theory, some on the integration of STEM curriculum, some on STEM literacy and competence, and some on STEM ethnic, gender, and country [3]. In addition, several studies have looked at STEM professional development and future citizenship [4]–[6]. The core purpose of this research is still the development of students. Students are the core of educational development, and STEM is no exception. How to cultivate students with 21st-century skills, how to enhance students' interest in STEM subjects, and how to find more suitable learning methods, these are all challenges that are still faced in the development of STEM [7], [8]. Due to the short

development time of STEM education, both theory and practice need to be further explored, and educators have recognized the potential problems in practice.

Notwithstanding so many opportunities and benefits STEM education provided, there are still unresolved challenges due to differences in its instruction purpose, objectives and educational environment [9]. Researchers try a variety of STEM styles, formal and informal STEM focus on the differences between STEM in schools and communities [10], the impact of information technology integration in classrooms versus traditional classrooms on STEM learning [11], gender differences in STEM and educational equity [12], and competencies cultivation of students in STEM [13], student-centered and teacher-centered learning models, exploration of learning theories [14]. However, educational research is rarely dichotomous, and persistent scholarly debates surrounding research outcomes have persisted throughout the evolution of STEM, the scarcity of studies adopting an overall perspective to examine the PBL-STEM frameworks, this study investigates the internal logical and developmental trajectory of PBL into STEM educational paradigms with a massive research and analysis.

Project-based learning (PjBL) and problem-based learning (PrBL) is a hot topic in education research in this decade. With its concept of immersive learning experience and solving real-world problems, especially in the background of the world's technological changes and rapid social development, supports learners to acquire practical skills necessary for future career development, PBL has won the favour of all countries and education fields [15], [16]. In the past period, the interest in PBL has led to a surge in research, this study generates a large number of reviews on the topic of PBL integration into STEM education. The literature traces back to the conclusions of the earliest and current studies on this topic. Considering the social needs and the basic logic of educational development, this method provides researchers gain deeper insights into this field and predicts future trends of PBL integration into STEM education. Although many studies have used similar approaches, in the past these studies either focused on one discipline, such as using PBL in nursing to improve student motivation [17], or only focused on data from Web of Science database and limited the string to a small range, such as focusing only on the field of STEM teacher training [18]. Therefore, previous studies exhibit certain limitations, this study covers a broader and more comprehensive range. Moreover, this study adopts the PRISMA framework alongside Bibliometric analysis, and Sankey diagrams analysis to explore the trend and potential future directions of PBL-STEM education.

Evidence shows that PBL is one of the most common approaches in STEM education [18]. How PBL integrated into STEM? What problems and challenges exist in this process? How does current research respond to these challenges? What are the future research directions? These issues are worth exploring, existing research does not provide a comprehensive and clear understanding of the development trends and problems of PBL in STEM education. PBL includes PjBL and PrBL in this article, the reason why these two kinds of PBL are not strictly distinguished is that both PjBL and PrBL are based inquiry learning and both center on students' active study, focusing on learning objectives, integration and construction of knowledge, and cultivating students' 21st-century skills such as creativity, critical thinking, cooperation and communication. In addition, during the literature search, we found that there is still no strict conclusion about the description method, implementation steps and process of PBL, for example, project-based learning is abbreviated as PBL or PjBL and other expressions as project-based approach or project-based teaching, this creates certain difficulties in retrieval. Some documents may be missed due to retrieval problems, which is also a limitation of this article. In this study, we define PBL as encompassing both PrBL and PjBL. We will use PrBL and PjBL to distinguish between them.

Using bibliometric analysis methods, this study explored researchers' perceptions of PBL-STEM education in high-quality academic articles published in SCOPUS journals. Specifically, this paper addresses the following key issues:

- What is the development of PBL-STEM education? It includes 3 questions:
  - i) How many SCOPUS journals be published?
  - ii) What is the profile of authors, countries and regions in published journals?
  - iii) What is the situation with the author's keywords?
- What is the development trend of PBL-STEM education? It includes 3 questions:
  - i) What are the trends in SCOPUS journal publication?
  - ii) What are the hot research directions about PBL-STEM?
  - iii) What are the future directions of research?

## 2. METHOD

### 2.1. Approach

This study screened the retrieved literature according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) standards, following the three steps of identification, screening and

included [19]. After excluding conference papers, news articles, reports, non-journal publications, and removing irrelevant topics, low-quality or duplicate studies, the included papers will utilize two bibliometric analyses with bibliometric coupling and co-word analysis. Keyword co-occurrence network and time series map analysis are constructed based on VOSviewer software. Besides that, content analysis was conducted based on the titles and abstracts to provide an in-depth interpretation of the research content.

**2.2. Data collection**

PRISMA process is used to search the literature to ensure the rigor of this study, data was collected in SCOPUS database in July 2024, by using the “TITLE-ABS-KEY”, excluding STEM cell, that is, medical definition related literature, shows in Table 1, when searching PBL, all keywords PBL, PjBL, PrBL, project-based learning and problem-based learning are included, in this step 8038 results are retrieved and 2306 papers are screened. Further sorting, select article in document type, restrict the source type to journal, select final in publication stage, set the limit language to English, and 2123 documents selected, PRISMA search strategy shows like Figure 1. Export cvs-formatted data document for further filtering, after re-examining the paper titles, keywords and abstracts, 124 papers with irrelevant topics and reviews were eliminated, and the remaining 1999 papers were further analysed.

Table 1. Keywords search from SCOPUS

No	TITLE-ABS-KEY	Rationale
1	“STEM*” or “STEAM” or “STEM education” or “STEAM education” or “science education” or “technology education” or “engineering education” or “mathematics education” and not “STEM cell”	To identify literature related to STEM
2	“PBL” or “PjBL” or “PrBL” or “project-based learning” or “problem-based learning”	To identify literature related to PBL

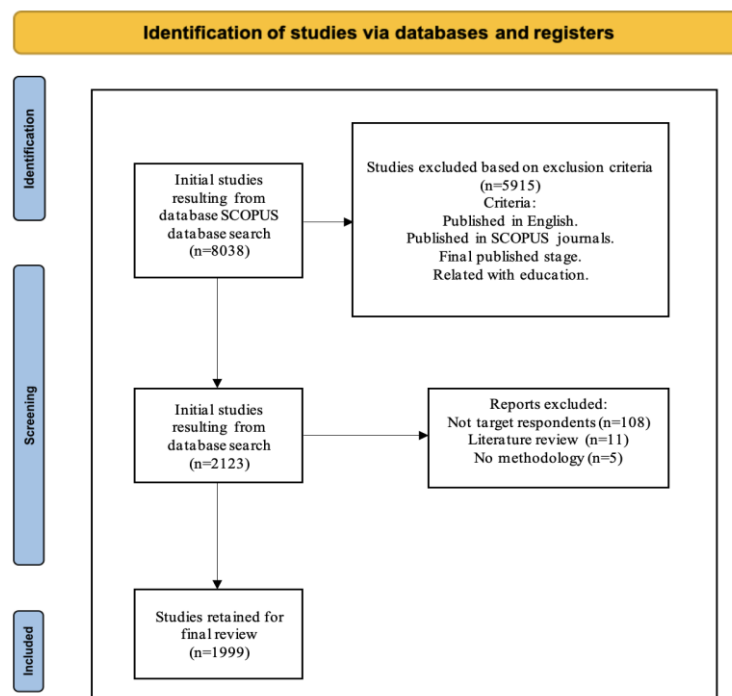


Figure 1. Search strategy based on PRISMA 2020 standard

Bibliometric assessment includes dynamics and structure analysis, the dynamics analysis includes publications and releases, publication timelines, and research terms, keyword frequency, citation number and distribution, as well as other influencing factors, such as high citation frequency [20], [21]. The structure analysis consists of word count map, co-occurrence network, thematic map and collaborative co-citation network, terms, keyword frequency, citation count and distribution, and other bibliometric impact indicators such as H-index. VOSviewer software was used to analysis the countries and regions publication distribution, author collaboration and keywords co-occurrence relationship [20], [22]. In VOSviewer, create a map based

on bibliographic data and new project, select read data from SCOPUS, find the corresponding file, finally perform bibliographic mapping to generate corresponding maps.

### 3. RESULTS

#### 3.1. Publication condition

The annual distribution of these 1999 literatures and corresponding cumulative results is shown in Figure 2. The first paper in the SCOPUS database documenting the application of this theme was published in 1978 by Gault and Snyder [23], entitled “An Undergraduate Design/Project Course Utilizing a Microcomputer” and published in IEEE Transaction on Education. It was an exploration of PjBL based on microcomputer courses in electrical engineering and was considered to provide electrical engineering students with one of the best PjBL experiences at the time [23]. Before 2003, there were few studies on PBL in STEM and the publication grew slowly, indicating that this period was in its infancy. After that, the integration of PBL and STEM has become closer, and the number of studies has increased exponentially, indicating that the world gradually attaches importance to the exploration of PBL and STEM integration during this period with the trend is continuing. In this data collection stage, some papers published early in the 2024 are also included to reveal more comprehensive data.

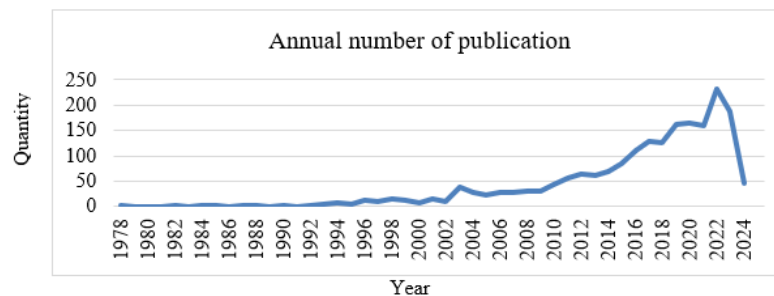


Figure 2. Trends of publication times and volume

In terms of sources, authors, and countries of publication, we sorted out high-yield journals and high-yield authors, as well as countries and regions with a high proportion of weight, shows in Table 2 to Table 4. Table 2 lists the top 10 sources in the topic that PBL integrated into STEM education field, the most journal in this topic is the International Journal of Engineering Education, which has published 216 articles with 2936 citations, and the European Journal of Engineering Education followed closely with 121 publications and 3443 citations. These top 10 sources published 675 articles and account for 33.5% of all publications.

Table 2. Journal source and publication situation

Rank	Source	TP	TC	%
1	International Journal of Engineering Education	216	2936	10.8
2	European Journal of Engineering Education	121	3443	6.0
3	IEEE Transactions on Education	106	3074	5.3
4	Computer Applications in Engineering Education	46	578	2.3
5	Journal of Engineering Education Transformations	37	110	1.8
6	Education Sciences	33	363	1.6
7	Journal of Professional Issues in Engineering Education and Practice	31	888	1.5
8	Sustainability Switzerland	30	267	1.5
9	International Journal of Technology and Design Education	29	1521	1.4
10	Eurasia Journal of Mathematics, Science and Technology Education	26	828	1.3

Note: TP is total number of publications, TC is total number of citations, and % is percentage.

In bibliometric analysis, the number of publications and citations is an important indicator of research ability and world recognition [24]. In order to ensure the cluster's dependability, after many adjustments we finally found a threshold [25]. Below the set threshold, statistical analysis of the data shows that in all the selected literature, the top ten cited authors are shown in Table 3, and there are two inclusion criteria for author's publication, one is the number of citations and the other is the number of journal

publications. The list of the top ten authors is ranked according to all citations, of which Kolmos is ranked first by publishing 24 papers with 1686 citations.

**Table 3. Author’s publication counts and citations**

Author	Papers	Citations	Total link strength
Kolmos, Anette	24	1686	21
Lou, Shi-Jer	11	538	11
Han, Sunyoung	6	510	3
Krajcik, Joseph	6	497	0
Belland, Brian R.	7	463	0
Tseng, Kuo-Hung	7	409	10
Du, Xiangyun	15	365	14
Fernandes, Sandra	6	279	3
Lima, Rui M.	7	242	6
Halim, Lilia	5	236	0

The most publications with countries and regions shown in Table 4. According to the two criteria of the number of papers and the number of citations, the top 20 countries or regions are selected. In the table of the number of papers, the standard of the 20 countries or regions that have published 30 papers or more is selected, it is selected based on the criteria of 20 countries or regions with more than 500 citations.

The United States demonstrates a clear dominance in the field, publishing 691 papers and receiving 24033 citations, ranking first globally and accounting for 34.57% of all papers included in this study. This leading position in both publication volume and citations underscores the United States’ authority and extensive experience in exploring and implementing PBL in STEM education. Furthermore, its research findings are widely referenced by scholars worldwide. Among the top 10 countries or regions, the number of citations ranges from 1200 to 3000, while the number of publications varies between 62 and 160. Notably, when integrating data from mainland China, Hong Kong, and Taiwan, China collectively ranks second in terms of both citations (4291) and publications (228). This consolidated result highlights China’s emerging leadership in advancing PBL in STEM, sharing a dominant position alongside the United States. Australia also stands out with 2988 citations, ranking fifth in publication volume but second in citation count, indicating significant international recognition of its research contributions. Similarly, Malaysia performs commendably, ranking within the top six for publications, demonstrating its growing focus and potential in STEM research. Other countries, including Spain, the United Kingdom, Denmark, Canada, and Turkey, are also active contributors and innovators in the field of PBL in STEM education, as reflected in their notable publication and citation metrics. Collectively, these findings emphasize the leadership roles of the United States and China in this domain, with the United States, in particular, playing a pivotal role in fostering international collaboration and driving global research progress.

**Table 4. Countries and regions with the most publications**

Total link strength	Sort by citations			Sort by documents			Total link strength
	Citations	Documents	Country or Region	Documents	Citations		
134	24033	691	United States	United States	691	24033	134
52	2988	101	Australia	Spain	158	2700	60
60	2700	158	Spain	China	113	1274	49
41	2645	79	Denmark	United Kingdom	103	1732	59
19	1782	81	Taiwan	Australia	101	2988	52
59	1732	103	United Kingdom	Malaysia	89	866	35
36	1379	74	Canada	Taiwan	81	1782	19
12	1362	61	Turkey	Denmark	79	2645	41
49	1274	113	China	Canada	74	1379	36
15	1235	34	Hong Kong	Indonesia	62	381	15
15	1150	39	Israel	Turkey	61	1362	12
23	966	25	Netherlands	India	58	466	15
15	934	50	Portugal	Portugal	50	934	15
35	866	89	Malaysia	Germany	48	820	48
48	820	48	Germany	Brazil	47	767	24
25	778	29	Sweden	Israel	39	1150	15
24	767	47	Brazil	Hong Kong	34	1235	15
27	729	24	France	South Korea	33	505	19
16	614	30	Finland	Italy	31	445	39
19	505	33	South Korea	Finland	30	614	16

We can get the same result by visualization; Figure 3 is a network visual map of cooperation between countries or regions. Through the visual expression of VOSviewer, PBL cooperation between countries or regions in STEM fields is expressed, where the size of each point, the frequency and thickness of the connection all reflect the intensity and scope of cooperation to different degrees. The Figure 3 shows that all countries or regions have cooperative relations in the field of STEM, among which the US is at the absolute center and has direct and indirect relations with many countries or regions. In addition, in Europe, the UK, Spain and other countries have close cooperation in this field, and STEM education is active in Asia, China, Malaysia, Indonesia and India.

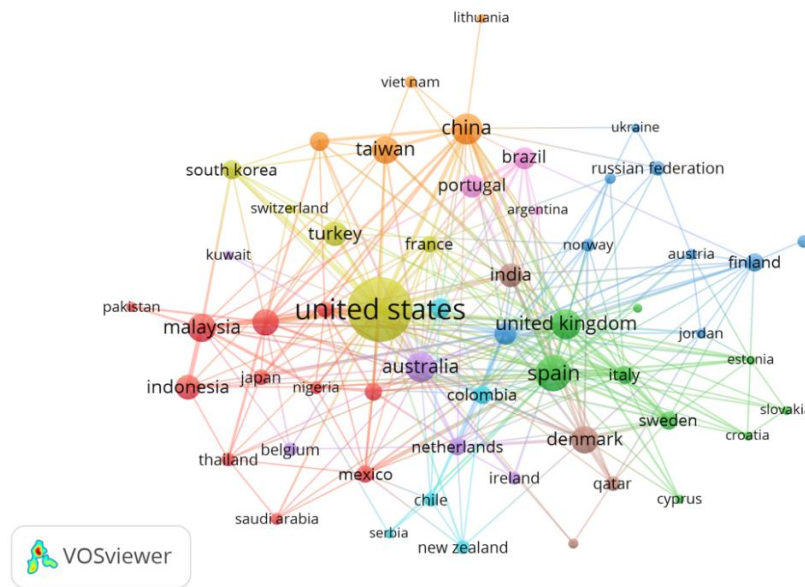


Figure 3. Network visualization map of international collaboration among countries and regions

To evaluate the recognition and impact of PBL-STEM research, the 1999 articles were categorized by citation counts shows in Table 5. Citation thresholds were defined as uncited (0), low cited (1-10), moderate cited (11-50), high cited (51-100), very high cited (>100). Compared between these 5 citation levels, the results indicates that a substantial proportion of articles (58.88%) were cited fewer than 10 times, while 12.66% were entirely uncited. In contrast, only 3.45% of the articles achieved very high citation counts (100+ citations). Notably, the top frequent author keywords across all citation categories were basically consistent, terms also show in table, appeared prominently regardless of citation level. Very high cited and high cited focus on foundational terms indicates their centrality to the field and reflects research bridging pedagogy and workforce readiness. Uncited and low cited shows that emerging and context-specific studies, Moderate Cited highlights growing interest in cross-disciplinary and social skill development. Articles with different dimensions show different performance in citation distribution, but they are all within the framework of PBL-STEM, those reveals that while these themes are central to the PBL-STEM field, they do not correspond to higher citation impact, the possible underlying reasons are multifaceted, involving countries and regions, the authority of sources, changes in research hotspots, and so on.

Table 5. Visibility and distribution of citations

Citation count	Papers count	Percentage (%)	Hotspot themes
VC	69	3.45	PjBL, STEM, PBL-STEM, pedagogy, higher education, innovation
HC	102	5.10	PrBL, engineering education, 21st-century skills, assessment, STEM literacy
MC	651	32.57	Interdisciplinary, critical thinking, collaborative learning, curriculum design, STEAM
LC	924	46.22	PjBL, soft skills, e-learning, computational thinking, COVID-2019
U	253	12.66	STEM curriculum, robotics, design thinking, sustainability, active learning

Note: VC is very high cited (>100 citations), HC is high cited (51-100 citations), MC is moderate cited (11-50 citations), LC is low cited (1-10 citations), and U is uncited (0 citations).

**3.2. Keywords co-occurrence analysis**

Keyword contribution analysis is suitable for identifying and exploring cutting-edge and emerging topic trends in the PBL research field in STEM, and the research proves that analysing the co-occurrence frequency of keywords in publications can provide insight into major themes and research trends [26], and the theoretical basis of co-occurrence analysis is that when two items are related to some extent, they will appear in the same literature at the same time [14]. VOSviewer uses keyword analysis to analyse the patterns and relationships of keywords or terms in a database [27]. The results show that there are more than 8,000 keywords in 1999 articles on related topics, and 4352 author keywords, and there are 5709 index keywords. We analysed the co-occurrence frequency of author keywords, set the occurrence of each keyword to more than 13 times, and obtained 54 keywords, which were divided into 7 clusters, whereas all those clusters are intercorrelated [25]. Figure 4 shows the co-occurrence network of author keywords for PBL-STEM research trends, from the results of the Figure 4, the larger the circle represented by each keyword, the more widely used the keyword by the author, and the closer the connection between the keyword and other keywords [24]. The Figure 4 also shows the keywords of 7 clusters in the contribution keyword network. The statistical table of 7 cluster highly related words is shown in Table 6.

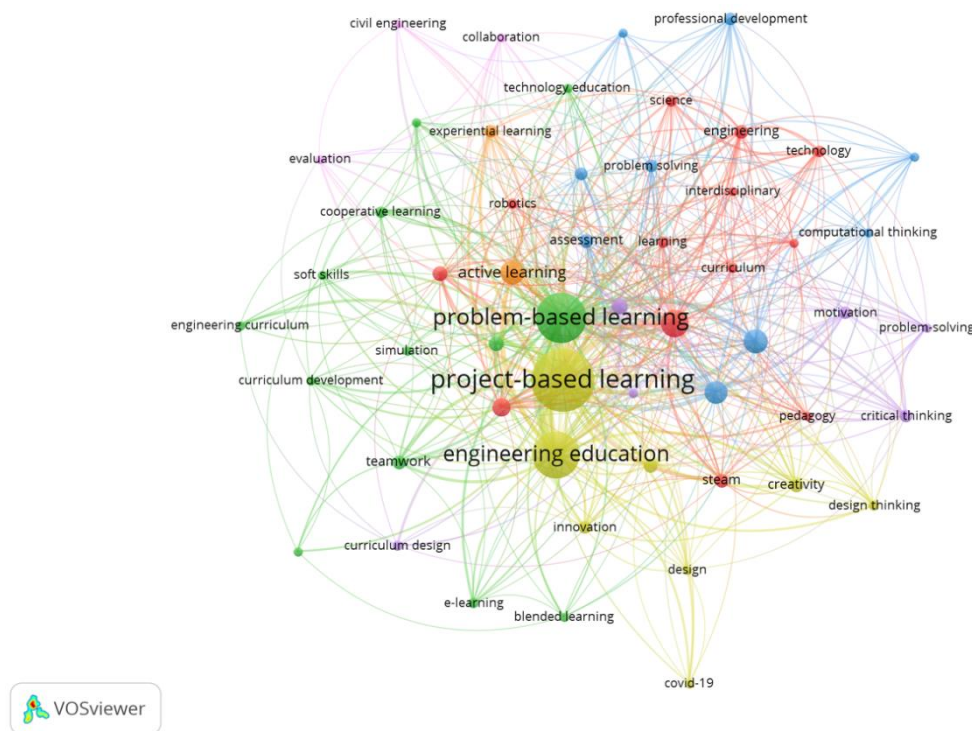


Figure 4. Network visualization of author’s keywords co-occurrence

Table 6. Keywords and main perspective

Cluster	Keywords	Main perspective
1	STEM, STEAM, curriculum, education, engineering, interdisciplinary, learning, mathematics, pedagogy, robotics, science, technology, sustainability	Application context of PBL in STEM
2	Problem-based learning, blended learning, collaborative learning, cooperative learning, curriculum development, e-learning, engineering curriculum, professional skills, simulation, soft skills, software engineering education, teamwork, technology education	PrBL method and literacy in STEM
3	Assessment, evaluation, case study, computational thinking, computer science education, mathematics education, problem solving, professional development, science education, STEM education	Evaluation and STEM development
4	Project-based learning, creativity, design, design thinking, engineering design, engineering education, innovation, COVID-19	PjBL method and learning outcomes in STEM
5	Critical thinking, curriculum design, electrical engineering, higher education, motivation	PBL curriculum construction and development in STEM
6	Civil engineering, collaboration	Curriculum integration
7	Active learning, experimental learning	PBL implement methodology in STEM education

The most popular keywords are problem-based learning, project-based learning and engineering education, which proves that PBL is the most widely used and researched in the field of engineering education in STEM education. The corresponding curriculum teaching method, learning mode, curriculum design, learning effect and evaluation are all included in the basic educational research process. In the research trend visualization Figure 5, according to author keywords frequency and overlay visualization diagram, it can be seen that in the context of PBL, STEAM integrated into ART, student's soft skills, interdisciplinary, blended learning, computational thinking are relatively new topics in recent studies. These keywords, such as STEAM, have a frequency of 33 times, which is significantly less than the 118 times of STEM. At the same time, STEAM is associated with interdisciplinary, design thinking, computational thinking, critical thinking, motivation, active learning and robotics are closely related, and these are relatively new research topics in the last five years. In addition, the application of PBL in blended learning has risen due to the pandemic of COVID-19, shows it is also a relatively emerging research direction; however, the outbreak of COVID-19 has controlled, the research will be not continued as previous, but the problem of the connection between education and social development reflected is worth consideration. Recent trends indicate a growing interest in interdisciplinary approaches (STEM-PBL, iSTEM, STEAM+), blended learning, and the integration of computational and critical thinking skills. These trends reflect the evolving educational needs in response to technological advancements and societal changes, such as the COVID-19 pandemic.

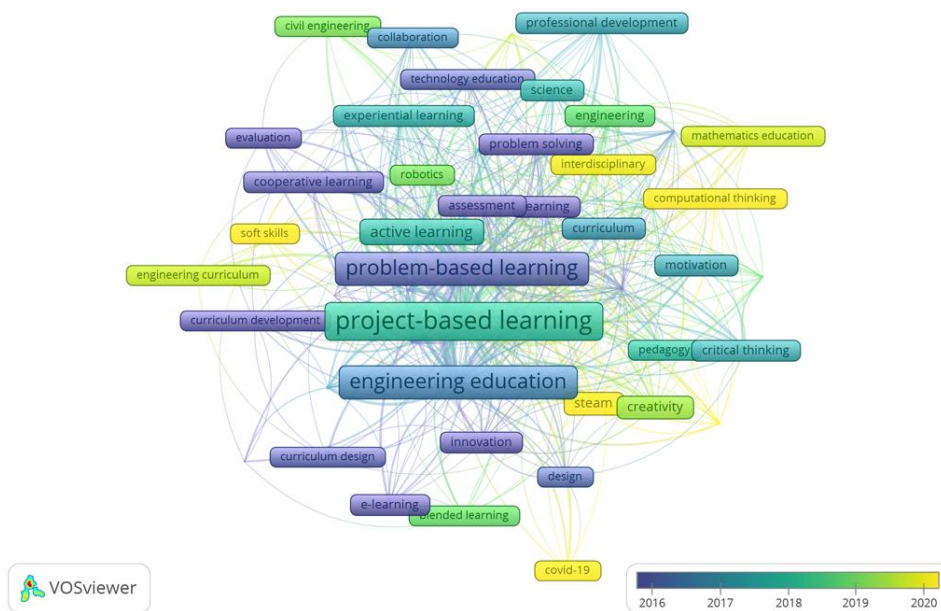


Figure 5. Overlay visualization of author's keywords co-occurrence

In that case, Figure 6 visually represents the evolution of trends in PBL-STEM education over time. The timeline highlights key stages in the development of research focus areas from 2000 to the present. From 2000 to 2005, the early PBL studies in STEM, initial research focused on integrating PBL into STEM education, studies explored its feasibility, pedagogical benefits and impact on student engagement [28]. From 2005-2010, curriculum design and assessment, this stage research emphasis shifted to designing PBL based STEM curricula and evaluating learning outcomes, researchers studied how PBL improves problem-solving skills, critical thinking, and student motivation [29]. From 2010 to 2015, the main topic is integration of new technologies, with the rise of digital learning tools, PBL methodologies began incorporating simulations, online platforms, and virtual labs to cultivate student engagement, STEM education adapted flipped classroom and blended learning strategies [30]. From 2015 to 2020, blended learning was developing rapidly, research focused on soft skills, blended learning approaches combined face-to-face and online PBL activities to improve flexibility and accessibility, and studies beyond technical knowledge, emphasising collaboration, teamwork, and professional skills [31], [32]. From 2020-2023, a special stage because of COVID-19 pandemic, all learning methodologies were influenced by the pandemic, social public event accelerated the shift to a fully online PBL approach due to distance learning challenges. Studies explored the effectiveness

of virtual teamwork, distance experiments, and digital assessments in PBL-STEM education [33], [34]. After 2023, AI, robotics, and interdisciplinary approaches be focused on and AI-driven adaptive learning systems, intelligent tutoring, and automated assessment methods are gaining attention in PBL research [35].

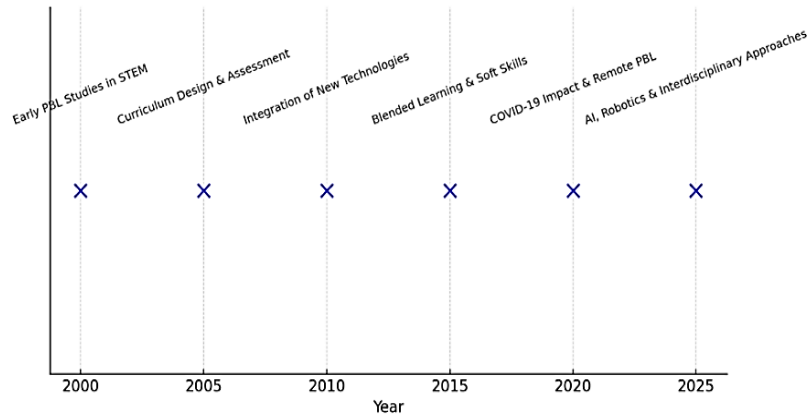


Figure 6. Evolution of PBL-STEM research trends

Sankey diagrams effectively visualize the flow relationships between different nodes within a system, making them particularly suitable for representing the transfer of energy or information. These diagrams can simultaneously display multi-stage flow processes, therefore revealing the overall structure of complex systems and identifying critical pathways [36]. In this study, we set years and research topics as system nodes, representing distinct states, while the links between nodes signify energy flows, with their widths proportional to the flow values. After applying threshold filters, we generated two Sankey diagram visualizations depicting the evolving hotspots in PBL-STEM research from 2020 to 2024, to complement the visualization results of thematic evolution analysis, shown in Figure 7 and Figure 8.

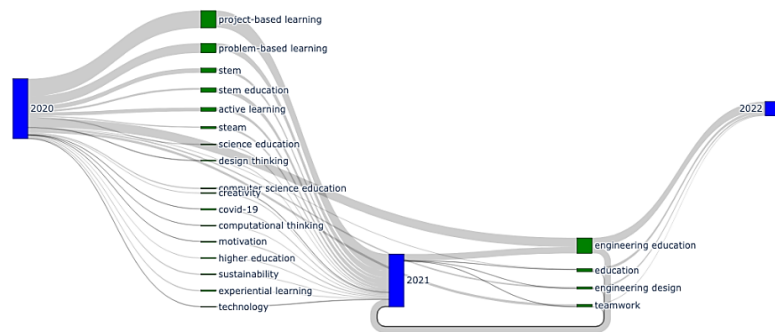


Figure 7. Sankey’s flow of research PBL-STEM 2020-2022

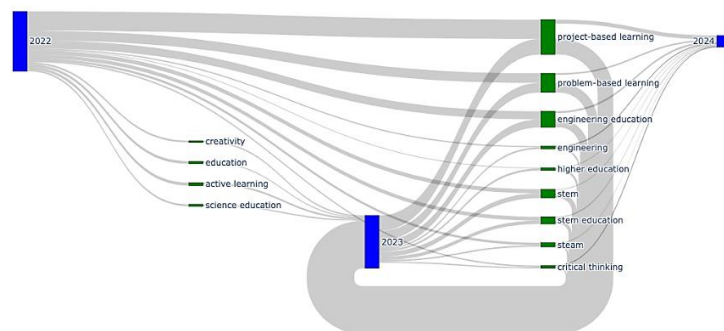


Figure 8. Sankey’s flow of research PBL-STEM 2022-2024

Sankey diagrams Figures 7 and 8 divide the research focus of PBL-STEM from 2020 to the present into two phases: 2020-2022 and 2022-2024. It is evident that both PjBL and PrBL have remained fundamental methodologies in STEM education across these stages, emphasizing active learning while highlighting teamwork, creativity, critical thinking, and computational thinking abilities [37]–[40]. Over the years, the primary research focus of PBL-STEM has continuously evolved in alignment with educational environments and reform trends, significantly influenced by advancements in educational technology.

#### 4. DISCUSSION

This study reveals the descriptive characteristics, research trends, and existing problems of the research data on the integration of PBL-STEM education published in SCOPUS journals, including the number of papers published, leading journals in the field, country research and author research trends, as well as keyword networks and hot issues. Initially, 8038 literatures related to the application of PBL in STEM education were searched in the database. After further setting screening conditions, it was determined that the number of literatures was reduced to 2123. After unifying the description of PBL, the abstracts and keywords of these literatures were reviewed, and 124 literatures unrelated to the topic or not directly related to this study were eliminated, 1999 papers were finally selected for analysis.

##### 4.1. Focus on the positive role of PBL in the global STEM education strategy

The integration of PBL-STEM education has seen exponential growth, especially in the last decade. This indicates a strong global interest and recognition of the benefits of PBL in enhancing STEM education. From the timeline and publication figure, we can see that the growth trend of PBL since its application in STEM education is exponential. From the 1980s when STEM was emerging to the early 21st-century, the research growth was slow. In the new century, as countries gradually attached importance to the development of national and scientific technology [41], and the sharp increase in social demand for STEM talents has led to the rapid growth of PBL-STEM field [42], especially in the past 10 years after 2013. Since we need to explore the latest research trend and development direction, the literature published in 2024 is also within the scope of our analysis. The data from 2024 to the literature search day show that the trend of PBL-STEM continues to grow, indicating that after decades of practice and exploration, the education community still attaches importance to its development.

After 2014, many countries promulgated policies on STEM, which greatly stimulated the development of STEM education. For example, The United States promulgated the New Five-Year Federal Strategic Plan in STEM Education in 2013 and STEM 2026: A Vision for Innovation in STEM Education in 2016, a new bill for STEM named Progress Report on the Implementation of the Federal STEM Education Strategic Plan was published in 2023 [43], in addition, the White House has released a lot of policies and bills to support STEM education; China promulgated Guiding Opinions on the Comprehensive and in-depth Promotion of Education Informatization during the 13th five-year in 2015, after two years, the Chinese STEM education white paper was released, which emphasized the implementation of STEM education in all education stages and the pilot of PBL education method. Australia released the National STEM School Education Strategy 2016-2026, support STEM development from the national strategy [44]. The United Kingdom also published Building Our Industrial Strategy-Green Paper in 2017, and in Japan, they mentioned PBL integration STEM into AI technology in their primary and secondary education. The proposal of these national level policies and bills further stimulated the research of STEM education.

According to our data, reveals that countries worldwide are actively exploring the integration of PBL in STEM education, and as the origin of STEM education, the United States maintains a leading position, with significantly higher publication and citation volumes in STEM education literature compared to other nations. However, the performance of different countries such as China, Australia, Denmark, Spain have also demonstrated strong advancements in STEM education, which is reflecting to their strategic orientation and national development plans. For instance, China's investment in STEM education has been continues growth, and supported by the development of domestic education innovation. The United Nations Educational, Scientific and Cultural Organization or UNESCO has established the International Institute for STEM Education (UNESCO IISTEM) in Shanghai [45]. This center undertakes the task of global STEM education development, which underscoring China's dual focus on fostering its own educational development while enhancing its global influence. Similar situations have also been observed in other countries and regions, highlighting the strategic role that PBL-STEM plays globally within the context of multilateralism.

#### 4.2. Prioritize the influence of information technology and social change on educational technology

Through author's keywords co-occurrence network and overlay visualization, we analyze the novelty of the research and the interrelation of the topics, and emerging trends in integrating PBL-STEM. Recent studies have consistently demonstrated that the effectiveness of STEM education is closely related to students' learning methods, students' self-efficacy, students' self-development and teachers' development level, and the evidence supports that PBL has emerged as a highly effective approach, especially in engineering learning [46], [47]. We divide the development trend into two parts to analyze, prior to 2018, the research predominantly focused on curriculum development, instruction design, and learning evaluation [48]–[50]. Since 2018, the focus has shifted toward the impacts of new technologies and global events [51], [52], evidence showed that blended learning, computational thinking and creativity have highlighted the growth prominence as pivotal themes. It is worth noting that the attempt of PBL combined with e-learning or blended learning in STEM field became an emerging hot topic during the COVID-19 pandemic [34], [53], studies generally agree that PBL has had a significant positive impact on STEM during the pandemic [54].

Although research on COVID-19's impact on STEM education is expected to wane post-pandemic, the connection between social developments and education remains is an eternal subject of inquiry. The development of metaverse, artificial intelligence, big data, internet of things, quantum mechanics and other emerging technologies cannot be separated from the support of education [55], [56]. Coincidentally, today's diversified society with information explosion, in education field, multi-disciplinary and interdisciplinary integration development is advocated in all stages [57], [58], and the development of emerging technologies is more or less related to STEM. Interdisciplinary, integration and other disciplines are becoming prominent features in the STEM field. As information continues to proliferate in a highly diversified society, educational practices increasingly advocate for student-centered learning that incorporates emerging technologies-such as robotics, computer science, and artificial intelligence-into traditional learning paradigms. People pay attention to student-centered learning, integrating computer, robotics, artificial intelligence, and other emerging technologies closely related to current science and technology, trying to integrate emerging technologies into the original learning process, aims to achieve the purpose of cultivating students STEM literacy, improving STEM identity and learning motivation, there is no doubt a broad prospect for exploration in this hotspot.

#### 4.3. Emphasize the adaptation between instruction logic and STEM subjects

Besides PjBL, PrBL, STEM and STEM education, engineering education and science education are the most closely related to PBL-STEM. Engineering education is the most popular field for implementing PBL, and technical education and mathematics education account for a small proportion, which is related to the nature and operability of the discipline. In addition, students' higher-order abilities, such as 21st-century skills and student ability cultivation, are also very important research in the integration of PBL-STEM education. An essential focus in integrating PBL-STEM education is the development of students' higher-order skills particularly 21st-century skills (including but not limited to the 4C skills, creativity, communication, critical thinking and collaboration) and other soft skills (such as design thinking, problem solving, and computational thinking).

Evaluation also emerges as a crucial aspect of this field, within the context of PBL-STEM education, evaluation and reflection form a continuous feedback loop that connects theoretical foundations, curriculum design, practical implementation, and assessment. This iterative process ensures that PBL practices are both effective and adaptable [59]–[61]. Additionally, the logic of learning practice affects the value identity of STEM education in all aspects, involves so many complex interplay factors such as teachers, students, classroom environments, curricula, and instruction methods [62]. By addressing these interrelated factors, PBL-STEM continues to evolve, emphasizing the logic of teaching with the adaptability of STEM, advancing its potential to foster meaningful educational outcomes [63].

#### 4.4. Implication

This study identifies several key trends that warrant further exploration and elaboration. Firstly, expanding research on blended and distance learning, particularly in the context of complex and changing international environments. Given the ongoing impact of unexpected events, research should investigate the effectiveness of blended and remote learning models in PBL-STEM education, understanding these dynamics can assist in developing resilient educational strategies. Secondly, international collaborations should be enhanced to share best practices, resources, and innovations in PBL integration into STEM. Collaborative projects and joint research can drive global advancements in this field. On the other hand, to strengthen the development of STEM teachers, the world has recognized the importance of STEM teachers and has gradually explored the composition of teachers' capabilities and training ways, invested in professional development programs for educators to effectively implement PBL methodologies, training teachers to design and facilitate PBL activities is crucial for the successful integration of PBL in STEM. Thirdly, since

emerging technologies promote the intellectualization and personalization of STEM education, the development of sound evaluation tools can effectively support the development of high-quality courses and the cultivation of high-level talent skills, accurately measure the impact of PBL on student outcomes, particularly higher-order skills such as critical thinking, creativity, and teamwork. Lastly, there be a focus on equity and diversity in STEM education, research should explore how PBL in STEM can be made more inclusive and equitable, ensuring that diverse student populations benefit from these educational strategies.

## 5. CONCLUSION

Compared with previous studies focused on a certain discipline, this study based on 1999 articles published by SCOPUS in the past 40 years, which has significant advantages in terms of time span, discipline coverage and data comprehensiveness, combined PRISMA standards with VOSviewer and conducted bibliometric analysis, effectively enhancing the systematicity and visibility of quantitative research. Through the analysis of the trend of publications, the potential for cooperation between different countries and regions, the layout of STEM education in different countries, the promulgation of policies and bills to support the development of STEM education, and the influence of social, economic, cultural and technological development on the development of STEM, especially the subversion of traditional education by emerging technologies were identified, revealed the evolution path of PBL-STEM. In a macro point of view, STEM education still maintains an upward research trend at present. In the next few decades, under the background of the current world development and reform, STEM education will still be a research hotspot. Of course, it is undeniable that the economic development gap between developed and developing countries, the differences in political background, social environment and cultural environment between countries in the world, and the different directions of national strategic development will bring challenges to the development of STEM education. However, the theme of world development is still integration and diversified development, and future STEM education will also move towards the integration of multi-race, multi-nationality, multi-country and region in its own trend of multidisciplinary integration development. In the micro perspective, STEM education will also link different disciplines such as computer, information technology, and artificial intelligence, towards to STEM+, which will provide more possibilities for the development of all aspects of STEM education in the future. This study reveals the development situation of integrating PBL-STEM education, and provides a part of the research basis for future researchers.

This research provides a comprehensive bibliometric analysis of PBL-STEM. The insights gained from this study are valuable for educators, policymakers, and researchers aiming to enhance STEM education through innovative teaching methods like PBL. By addressing the suggestions outlined, future research can further advance our understanding and implementation of PBL in STEM, ultimately contributing to the development of skilled and adaptable future professionals.

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C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

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## CONFLICT OF INTEREST STATEMENT

The authors declare there is no competing interests.

## DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [NAJ], upon reasonable request.

## REFERENCES





- [1] W. W. Chu, N. R. M. Hafiz, U. A. Mohamad, H. Ashamuddin, and S. W. Tho, "A review of STEM education with the support of visualizing its structure through the CiteSpace software," *International Journal of Technology and Design Education*, vol. 33, no. 1, pp. 39–61, 2023, doi: 10.1007/s10798-022-09728-3.
- [2] K. C. Margot and T. Kettler, "Teachers' perception of STEM integration and education: a systematic literature review," *International Journal of STEM Education*, vol. 6, no. 1, 2019, doi: 10.1186/s40594-018-0151-2.
- [3] S. L. Clark, C. Dyar, E. M. Inman, N. Maung, and B. London, "Women's career confidence in a fixed, sexist STEM environment," *International Journal of STEM Education*, vol. 8, no. 1, 2021, doi: 10.1186/s40594-021-00313-z.
- [4] L. B. Birney, J. Kong, B. R. Evans, S. Ceritelli, and M. Danker, "Experiential and real-world learning for teachers in the billion oyster project and curriculum and community enterprise (BOP-CCERS) for the restoration of New York Harbor with New York City Public Schools Program," *Journal of Curriculum and Teaching*, vol. 8, no. 4, pp. 30–35, 2019, doi: 10.5430/jct.v8n4p30.
- [5] J. M. Wolfand, K. A. Bieryla, C. M. Ivler, and J. E. Symons, "Exploring an engineer's role in society: service learning in a first-year computing course," *IEEE Transactions on Education*, vol. 65, no. 4, pp. 568–574, 2022, doi: 10.1109/TE.2022.3148698.
- [6] J. A. Gordillo Martorell, J. Martin-Torres, M. P. Zorzano Mier, T. Mathanlal, D. Cuartielles, and M. Johansson, "The infinite learning chain. Flipped professional labs for learning and knowledge co-creation," *Open Education Studies*, vol. 1, no. 1, pp. 151–176, 2019, doi: 10.1515/edu-2019-0011.
- [7] J. Chen, A. Kolmos, and X. Du, "Forms of implementation and challenges of PBL in engineering education: a review of literature," *European Journal of Engineering Education*, vol. 46, no. 1, pp. 90–115, 2021, doi: 10.1080/03043797.2020.1718615.
- [8] C. Wallwey, M. M. Longmeier, D. Hayde, J. Armstrong, R. Kajfez, and R. Pelan, "Consider 'HACKS' when designing hackathon challenges: Hook, action, collaborative knowledge sharing," *Frontiers in Education*, vol. 7, 2022, doi: 10.3389/educ.2022.954044.
- [9] K. Goodnough, S. Azam, and P. Wells, "Adopting drone technology in STEM (science, technology, engineering, and mathematics): an examination of elementary teachers' pedagogical content knowledge," *Canadian Journal of Science, Mathematics and Technology Education*, vol. 19, no. 4, pp. 398–414, 2019, doi: 10.1007/s42330-019-00060-y.
- [10] Y. Lee, R. M. Capraro, and A. Bicer, "Affective mathematics engagement: a comparison of STEM PBL versus non-STEM PBL instruction," *Canadian Journal of Science, Mathematics and Technology Education*, vol. 19, no. 3, pp. 270–289, 2019, doi: 10.1007/s42330-019-00050-0.
- [11] K. D. Su, "The challenge and opportunities of STEM learning efficacy for living technology through a transdisciplinary problem-based learning activity," *Journal of Science Education and Technology*, vol. 33, no. 4, pp. 429–443, 2024, doi: 10.1007/s10956-024-10094-z.
- [12] A. Caspi and P. Gorsky, "STEM career expectations across four diverse countries: motivation to learn mathematics mediates the effects of gender and math classroom environments," *International Journal of STEM Education*, vol. 11, no. 1, 2024, doi: 10.1186/s40594-024-00511-5.
- [13] D. Reider, K. Kneistis, and J. Malyn-Smith, "Workforce education models for K-12 STEM education programs: reflections on, and implications for, the NSF ITEST program," *Journal of Science Education and Technology*, vol. 25, no. 6, pp. 847–858, 2016, doi: 10.1007/s10956-016-9632-6.
- [14] J. A. Marín-Marín, A. J. Moreno-Guerrero, P. Dúo-Terrón, and J. López-Belmonte, "STEAM in education: a bibliometric analysis of performance and co-words in Web of Science," *International Journal of STEM Education*, vol. 8, no. 1, 2021, doi: 10.1186/s40594-021-00296-x.
- [15] W. Hung, "All PBL starts here: the problem," *Interdisciplinary Journal of Problem-based Learning*, vol. 10, no. 2, 2016, doi: 10.7771/1541-5015.1604.
- [16] S. L. Navy and F. Kaya, "PBL as a pedagogical approach for integrated STEM: Evidence from prospective teachers," *School Science and Mathematics*, vol. 120, no. 5, pp. 221–232, 2020, doi: 10.1111/ssm.12408.
- [17] I. S. Shin and J. H. Kim, "The effect of problem-based learning in nursing education: a meta-analysis," *Advances in Health Sciences Education*, vol. 18, no. 5, pp. 1103–1120, 2013, doi: 10.1007/s10459-012-9436-2.
- [18] D. Darmawansah, G. J. Hwang, M. R. A. Chen, and J. C. Liang, "Trends and research foci of robotics-based STEM education: a systematic review from diverse angles based on the technology-based learning model," *International Journal of STEM Education*, vol. 10, no. 1, 2023, doi: 10.1186/s40594-023-00400-3.
- [19] M. J. Page *et al.*, "The PRISMA 2020 statement: an updated guideline for reporting systematic reviews," *Systematic Reviews*, vol. 10, no. 1, 2021, doi: 10.1186/s13643-021-01626-4.
- [20] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, and W. M. Lim, "How to conduct a bibliometric analysis: an overview and guidelines," *Journal of Business Research*, vol. 133, pp. 285–296, 2021, doi: 10.1016/j.jbusres.2021.04.070.
- [21] N. J. van Eck and L. Waltman, "Visualizing bibliometric networks," in *Measuring Scholarly Impact*, Cham: Springer International Publishing, 2014, pp. 285–320. doi: 10.1007/978-3-319-10377-8\_13.
- [22] Q. Yu, K. Yu, B. Li, and Q. Wang, "Effectiveness of blended learning on students' learning performance: a meta-analysis," *Journal of Research on Technology in Education*, vol. 57, no. 3, pp. 499–520, 2025, doi: 10.1080/15391523.2023.2264984.
- [23] J. W. Gault and W. E. Snyder, "An undergraduate design/project course utilizing a microcomputer," *IEEE Transactions on Education*, vol. 21, no. 4, pp. 240–243, 1978, doi: 10.1109/TE.1978.4321253.
- [24] G. S. Colares *et al.*, "Floating treatment wetlands: a review and bibliometric analysis," *Science of the Total Environment*, vol. 714, 2020, doi: 10.1016/j.scitotenv.2020.136776.
- [25] N. L. Phuong *et al.*, "Implementation of STEM education: a bibliometrics analysis from case study research in Scopus database," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 19, no. 6, 2023, doi: 10.29333/ejmste/13216.

- [26] J. Liu, J. Li, and C. Fan, "A bibliometric study of pool fire related publications," *Journal of Loss Prevention in the Process Industries*, vol. 63, 2020, doi: 10.1016/j.jlp.2019.104030.
- [27] X. Chen, D. Zou, H. Xie, and F. L. Wang, "Past, present, and future of smart learning: a topic-based bibliometric analysis," *International Journal of Educational Technology in Higher Education*, vol. 18, no. 1, 2021, doi: 10.1186/s41239-020-00239-6.
- [28] V. Sukacke *et al.*, "Towards active evidence-based learning in engineering education: a systematic literature review of PBL, PjBL, and CBL," *Sustainability (Switzerland)*, vol. 14, pp. 1–31, 2022.
- [29] H. C. Kuo, Y. C. Tseng, and Y. T. C. Yang, "Promoting college student's learning motivation and creativity through a STEM interdisciplinary PBL human-computer interaction system design and development course," *Thinking Skills and Creativity*, vol. 31, pp. 1–10, 2019, doi: 10.1016/j.tsc.2018.09.001.
- [30] K. Brundiers and A. Wiek, "Do we teach what we preach? An international comparison of problem- and project-based learning courses in sustainability," *Sustainability (Switzerland)*, vol. 5, no. 4, pp. 1725–1746, 2013, doi: 10.3390/su5041725.
- [31] A. Raman, R. Thannimalai, Y. Don, and M. Rathakrishnan, "A bibliometric analysis of blended learning in higher education: perception, achievement and engagement," *International Journal of Learning, Teaching and Educational Research*, vol. 20, no. 6, pp. 126–151, 2021, doi: 10.26803/IJLTER.20.6.7.
- [32] C. T. Goode, M. Lamoreaux, K. J. Atchison, E. C. Jeffress, H. L. Lynch, and E. Sheehan, "Quantitative skills, critical thinking, and writing mechanics in blended versus face-to-face versions of a research methods and statistics course," *Teaching of Psychology*, vol. 45, no. 2, pp. 124–131, 2018, doi: 10.1177/0098628318762873.
- [33] O. Lee and T. Campbell, "What science and STEM teachers can learn from COVID-19: harnessing data science and computer science through the convergence of multiple STEM subjects," *Journal of Science Teacher Education*, vol. 31, no. 8, pp. 932–944, 2020, doi: 10.1080/1046560X.2020.1814980.
- [34] A. Charania, U. Bakshani, S. Paltiwale, I. Kaur, and N. Nasrin, "Constructivist teaching and learning with technologies in the COVID-19 lockdown in Eastern India," *British Journal of Educational Technology*, vol. 52, no. 4, pp. 1478–1493, 2021, doi: 10.1111/bjet.13111.
- [35] C. C. Chang and Y. K. Chen, "A transdisciplinary STEM course integrated through project-based learning on robotics: perspective from teacher and student feedback," *Asia Pacific Journal of Education*, vol. 45, no. 2, pp. 661–676, 2023, doi: 10.1080/02188791.2023.2209698.
- [36] C. Chong *et al.*, "A visualization method of the economic input–output table: mapping monetary flows in the form of sankey diagrams," *Sustainability (Switzerland)*, vol. 13, no. 21, 2021, doi: 10.3390/su132112239.
- [37] J. Goñi, C. Cortázar, D. Alvares, U. Donoso, and C. Miranda, "Is teamwork different online versus face-to-face? A case in engineering education," *Sustainability (Switzerland)*, vol. 12, no. 24, pp. 1–18, 2020, doi: 10.3390/su122410444.
- [38] Ting-Ting Wu and Yu-Tzu Wu, "Applying project-based learning and SCAMPER teaching strategies in engineering education to explore the influence of creativity on cognition, personal motivation, and personality traits," *Thinking Skills and Creativity*, vol. 35, no. 1, 2020.
- [39] C. Jiang and Y. Pang, "Enhancing design thinking in engineering students with project-based learning," *Computer Applications in Engineering Education*, vol. 31, no. 4, pp. 814–830, 2023, doi: 10.1002/cae.22608.
- [40] O. L. Ng, M. Liu, and Z. Cui, "Students' in-moment challenges and developing maker perspectives during problem-based digital making," *Journal of Research on Technology in Education*, vol. 55, no. 3, pp. 411–425, 2023, doi: 10.1080/15391523.2021.1967817.
- [41] L. Katehi, G. Pearson, and M. Feder, "Engineering in K-12 education: understanding the status and improving the prospects," *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, pp. 1–218, 2009, doi: 10.17226/12635.
- [42] F. B. Mota, B. P. Cabral, L. A. M. Braga, and R. M. Lopes, "Mapping the global research on project-based learning: a bibliometric and network analysis (2014–2024)," *Frontiers in Education*, vol. 10, 2025, doi: 10.3389/feduc.2025.1522694.
- [43] White House Office of Science and Technology Policy, "Progress report on the implementation of the federal STEM education strategic plan," Report, United States, 2024.
- [44] Australian Education Ministers, "National STEM School education strategy 2016-2026," Department of Education, Australia, 2015.
- [45] UNESCO, "Proposal for the establishment of a new category I institute in Shanghai, China," Paris, pp. 1–21, 2023.
- [46] K. S. Al-Olimat, "A step-by-step derivation of a generalized model coupled with questions formulation technique to teach different types of dc motors and its impact on student performance, the course, and the program," *IEEE Transactions on Education*, vol. 65, no. 2, pp. 184–190, 2022, doi: 10.1109/TE.2021.3108744.
- [47] P. K. Ningtyas, H. R. Widarti, P. Parlan, S. Rahayu, and I. W. Dasna, "Enhancing students' abilities and skills through science leaning integrated STEM: a systematic literature review," *International Journal of Education in Mathematics, Science and Technology*, vol. 12, no. 5, pp. 1161–1181, 2024, doi: 10.46328/ijemst.4292.
- [48] N. J. Hunsu, B. Abdul, B. J. Van Wie, O. Adesope, and G. R. Brown, "Exploring students' perceptions of an innovative active learning paradigm in a fluid mechanics and heat transfer course," *International Journal of Engineering Education*, vol. 31, no. 5, pp. 1200–1213, 2015.
- [49] A. Ruth *et al.*, "Engineering projects in community service (Epics) in high schools: subtle but potentially important student gains detected from human-centered curriculum design," *Education Sciences*, vol. 9, no. 1, 2019, doi: 10.3390/educsci9010035.
- [50] A. Kolmos, J. E. Holgaard, and N. R. Clausen, "Progression of student self-assessed learning outcomes in systemic PBL," *European Journal of Engineering Education*, vol. 46, no. 1, 2020, doi: 10.1080/03043797.2020.1789070.
- [51] N. M. Fonseca Ferreira and E. D. C. Freitas, "Computer applications for education on industrial robotic systems," *Computer Applications in Engineering Education*, vol. 26, no. 5, pp. 1186–1194, 2018, doi: 10.1002/cae.21982.
- [52] A. Gomoll, S. Šabanović, E. Tolar, C. E. Hmelo-Silver, M. Francisco, and O. Lawlor, "Between the social and the technical: negotiation of human-centered robotics design in a middle school classroom," *International Journal of Social Robotics*, vol. 10, no. 3, pp. 309–324, 2018, doi: 10.1007/s12369-017-0454-3.
- [53] A. E. Anderson, L. B. Justement, and H. A. Bruns, "Using real-world examples of the COVID-19 pandemic to increase student confidence in their scientific literacy skills," *Biochemistry and Molecular Biology Education*, vol. 48, no. 6, pp. 678–684, 2020, doi: 10.1002/bmb.21474.
- [54] E. C. Miller, E. Reigh, L. Berland, and J. Krajcik, "Supporting equity in virtual science instruction through project-based learning: opportunities and challenges in the era of COVID-19," *Journal of Science Teacher Education*, vol. 32, no. 6, pp. 642–663, 2021, doi: 10.1080/1046560X.2021.1873549.
- [55] B. K. Prahani, I. R. Dawana, B. Jatmiko, and T. Amelia, "Research trend of big data in education during the last 10 years," *International Journal of Emerging Technologies in Learning*, vol. 18, no. 10, pp. 39–64, 2023, doi: 10.3991/ijet.v18i10.38453.





- [56] M. Vargas *et al.*, “A project based learning approach for teaching artificial intelligence to undergraduate students,” *International Journal of Engineering Education*, vol. 36, no. 6, pp. 1773–1782, 2020.
- [57] S. Bell, A. Chilvers, L. Jones, and N. Badstuber, “Evaluating engineering thinking in undergraduate engineering and liberal arts students,” *European Journal of Engineering Education*, vol. 44, no. 3, pp. 429–444, 2019, doi: 10.1080/03043797.2018.1552663.
- [58] M. Woodrow, A. Gillen, R. Woodrow, and J. Torero, “Investigating varied pedagogical approaches for problem-based learning in a fire safety engineering course,” *International Journal of Engineering Education*, vol. 36, no. 5, 2020.
- [59] X. Gao, P. Li, J. Shen, and H. Sun, “Reviewing assessment of student learning in interdisciplinary STEM education,” *International Journal of STEM Education*, vol. 7, no. 1, Dec. 2020, doi: 10.1186/s40594-020-00225-4.
- [60] T. S. Chang, H. C. Wang, A. M. D. Haynes, M. M. Song, S. Y. Lai, and S. H. Hsieh, “Enhancing student creativity through an interdisciplinary, project-oriented problem-based learning undergraduate curriculum,” *Thinking Skills and Creativity*, vol. 46, 2022, doi: 10.1016/j.tsc.2022.101173.
- [61] E. Arce, A. Suárez-García, J. A. López-Vázquez, and M. I. Fernández-Ibáñez, “Design sprint: enhancing STEAM and engineering education through agile prototyping and testing ideas,” *Thinking Skills and Creativity*, vol. 44, 2022.
- [62] N. O. Awuor, C. Weng, E. J. Piedad, and R. Militar, “Teamwork competency and satisfaction in online group project-based engineering course: The cross-level moderating effect of collective efficacy and flipped instruction,” *Computers and Education*, vol. 176, 2022, doi: 10.1016/j.compedu.2021.104357.
- [63] S. K. Chen, Y. T. C. Yang, C. P. Lin, and S. S. J. Lin, “Dispositions of 21st-century skills in STEM programs and their changes over time,” *International Journal of Science and Mathematics Education*, vol. 21, no. 4, pp. 1363–1380, 2023, doi: 10.1007/s10763-022-10288-0.

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